
General Background
Natural Water Systems
Threats to Surface and Ground Water
Manmade Water Management Systems
DRINKING WATER ACADEMY
DWA
The Watershed Academy


Natural Water
Systems
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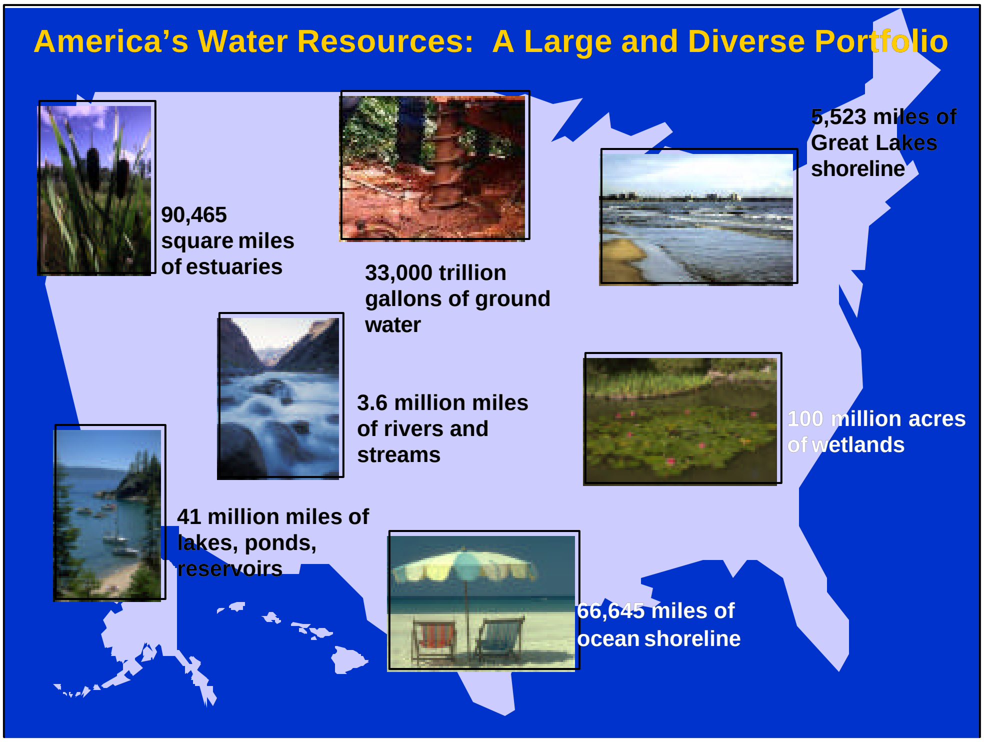
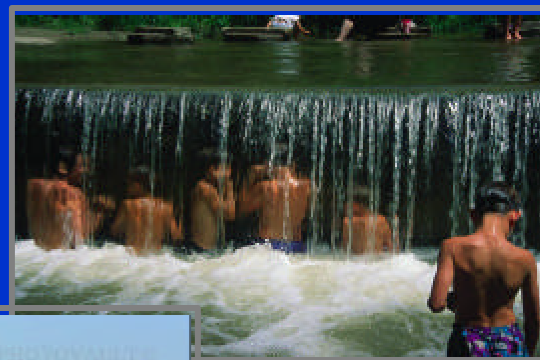

America's Water Resources: A Large and Diverse Portfolio
90,465 square miles of estuaries
33,000 trillion gallons of ground water
5,523 miles of Great Lakes shoreline
3.6 million miles of rivers and streams
100 million acres of wetlands
41 million miles of lakes, ponds, reservoirs
66,645 miles of ocean shoreline

Discussion

- What are the ways in which people use water?

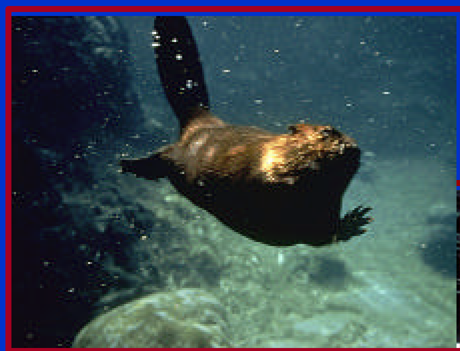

Public Water
Supply

Water-Based Recreation



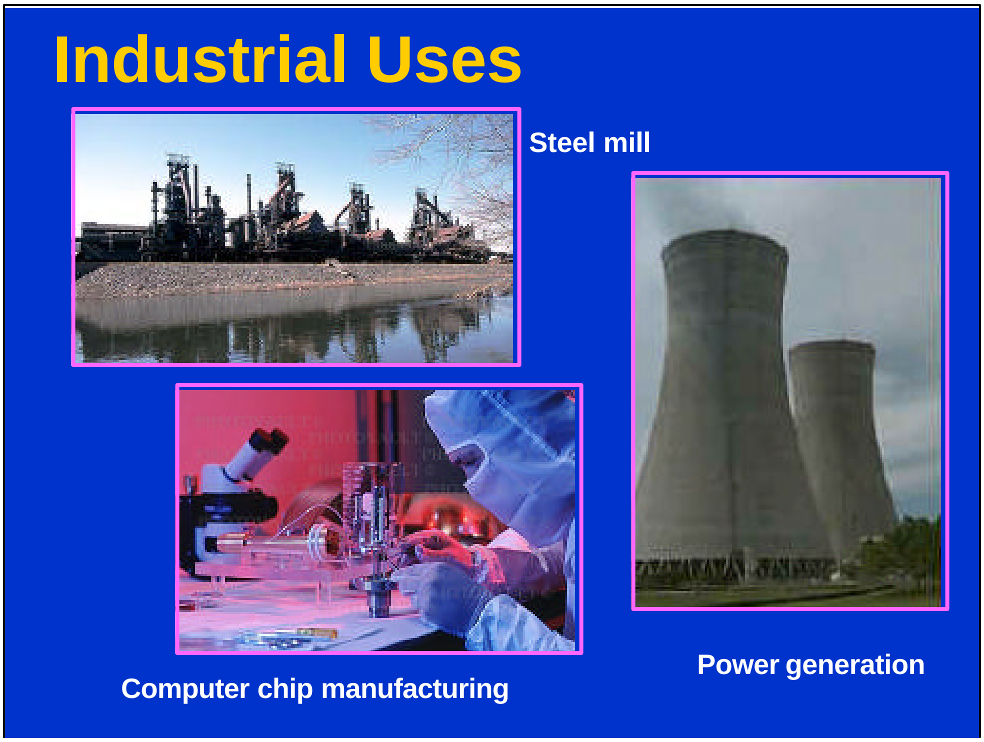
Commercial, Subsistence and Recreational Fishing

Aquatic Life and Wildlife

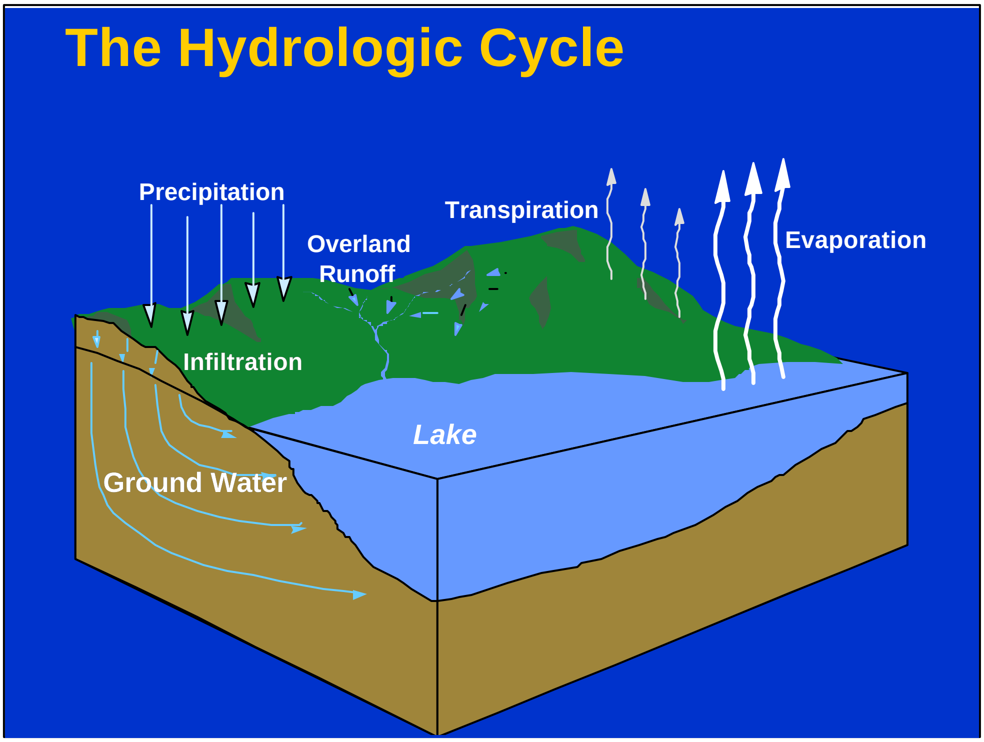



Wildlife
Dependent
on Aquatic
Food Chains

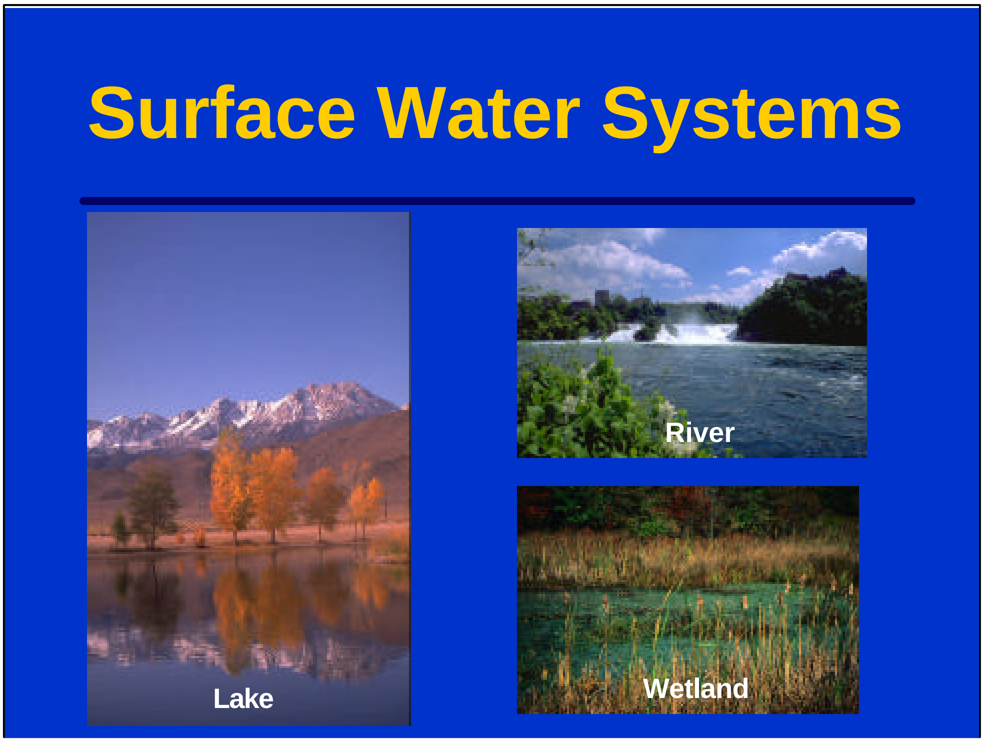
- In drier parts of the U.S., where irrigation is used to supplement natural precipitation, it may be important to maintain levels of certain parameters in surface waters that are used as sources of irrigation water at concentrations that will not harm cultivated plants or people that eat the plants or foods derived from them.



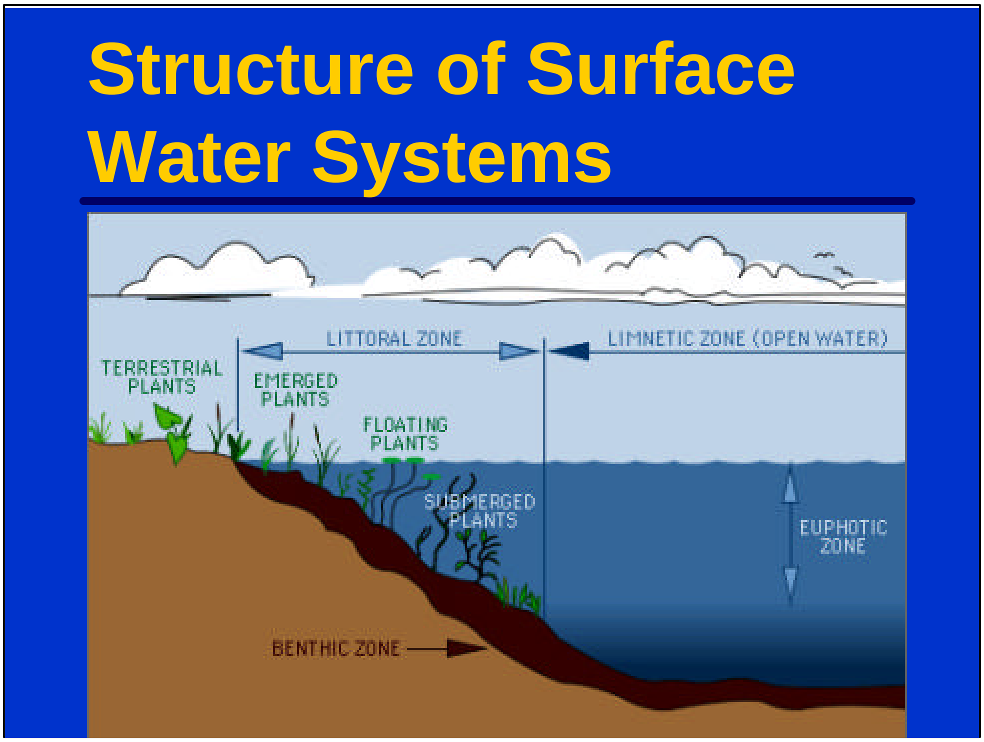
- Most industries need a reliable source of water to support operations. In 1995, the USGS estimated that manufacturing companies used more than 9 trillion gallons of fresh water per year. In many cases water is needed primarily for production purposes, such as in the manufacturing of computer chips or steel, and is treated and returned to a surface or ground water source.



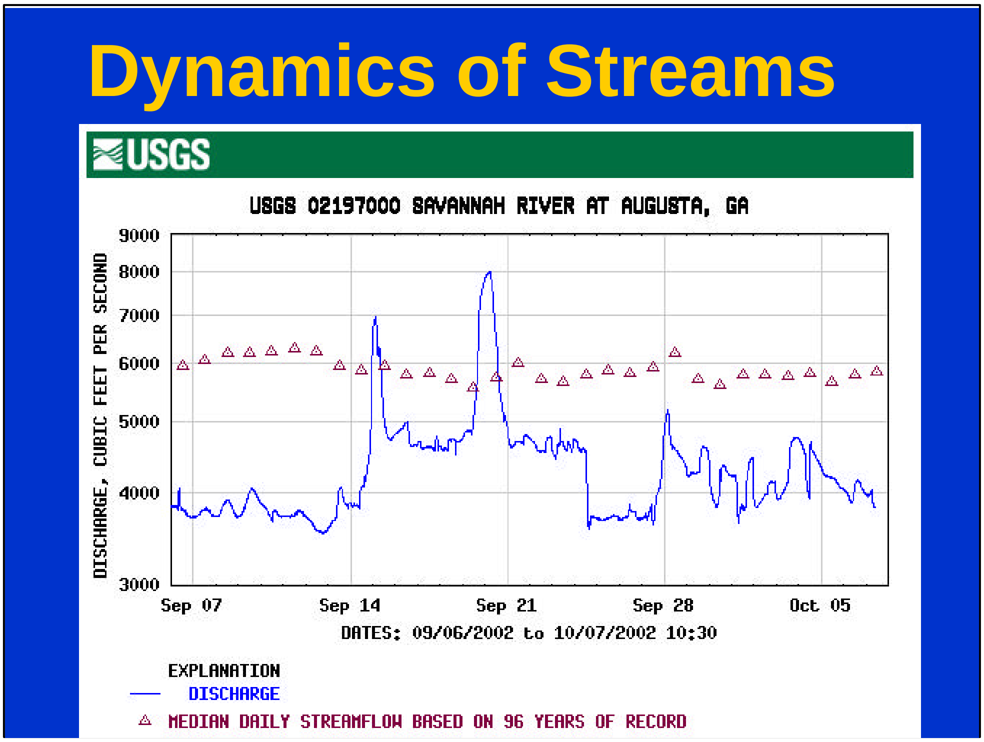
- There is a ***finite amount of water on the earth***. The water on the earth is used over and over again. The water cycle, or ***hydrologic cycle***, is the continuous movement of water from ocean to air and land then back to the ocean in a cyclic pattern.
  - The sun heats the Earth's surface water (lakes, rivers, oceans, estuaries) which causes it to ***evaporate***.
  - The water vapor rises into the Earth's atmosphere where it cools and condenses into liquid droplets.
  - The liquid droplets combine and grow until they become too heavy and fall to the Earth as precipitation. ***Precipitation*** falls from the atmosphere in the form of rain, ice, or snow. It reaches the land surface and recharges rivers, lakes, and other surface water bodies directly; ***infiltrates*** the ground and eventually reaches the ***ground water***; or evaporates back into the atmosphere.
  - Throughout the cycle, water is temporarily stored in lakes or glaciers, underground, or in living organisms.
- Water that exists beneath the land surface is called ***ground water***, while water at the surface is called ***surface water***.
- Within an aquifer, ground water flows in much the same way that surface water does, along natural contours such as pores and spaces between the soil and rocks within the subsurface. Where ground water flows intersect a stream or lake bed, the ground water can recharge that water body, or vice versa.
- A surface water body that is recharged by ground water is known as a ***gaining stream***. Where the water from the stream infiltrates to the ground water, the stream is known as a ***losing stream***. The direction in which water flows may vary throughout the year, depending on ground water and surface water levels at a given season. Left untouched, ground water naturally arrives at a balance, discharging and recharging depending on hydrologic conditions.



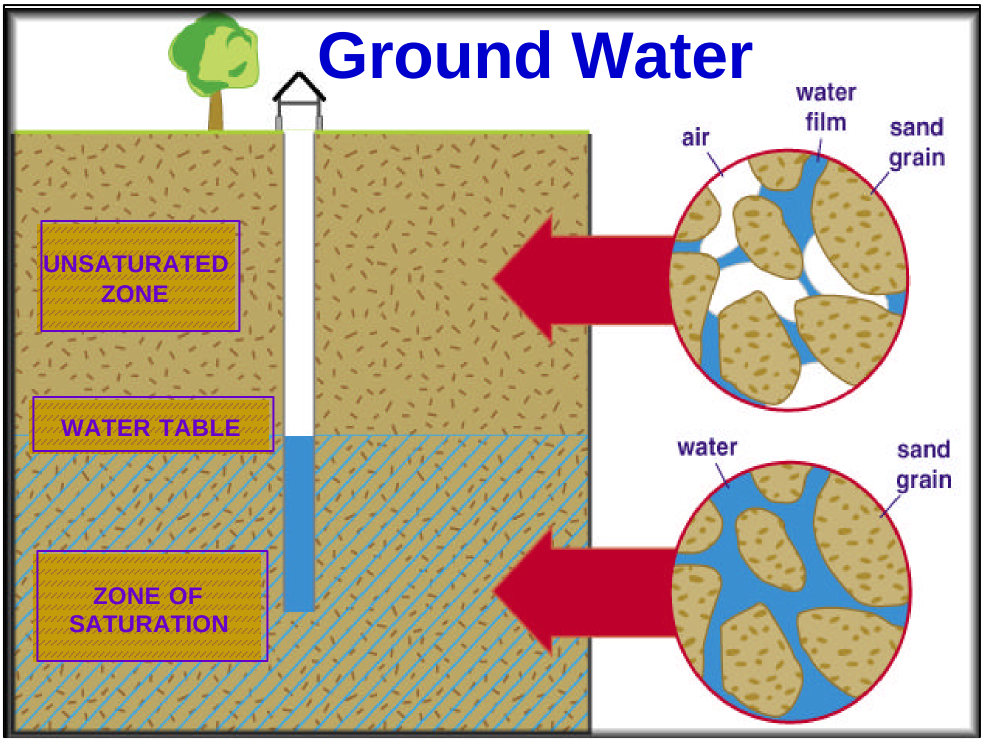
- Natural water systems include lakes, ponds, rivers, streams and wetlands. They are characterized as either ***lentic*** (still water) or ***lotic*** (flowing water).
- ***Lentic*** systems generally include ***lakes and ponds***. Most basin-type wetlands are also generally grouped within lentic systems; these are areas of constant soil saturation or inundation with distinct vegetative and faunal communities. Lakes and ponds are almost always connected with streams in the same watershed, but the reverse is not nearly as often true.
- ***Lotic*** systems include ***streams and rivers***. Streams and rivers depend on surface runoff (snow-melt and precipitation) and ground water for recharge. Those originating in mountainous areas are highly dependent on snow melt, while others, located in flood plains or less hilly regions, are more dependent on surface runoff from rain. Depending on the season, streams can become more dependent on ground water for recharge. For example, during the dry season (typically the summer months), streams rely more on ground water than on surface runoff from rain for recharge. During the winter months, snow melt is minimized, thus those streams dependent on snowmelt for recharge will also become more dependent on ground water.
- The water table is also dependent on precipitation events and human consumption. When a lot of water is pumped from an aquifer, or when there is a dry spell, the water table sinks lower. And after a heavy rain storm or flood event, water that percolates the soil will recharge the water table.



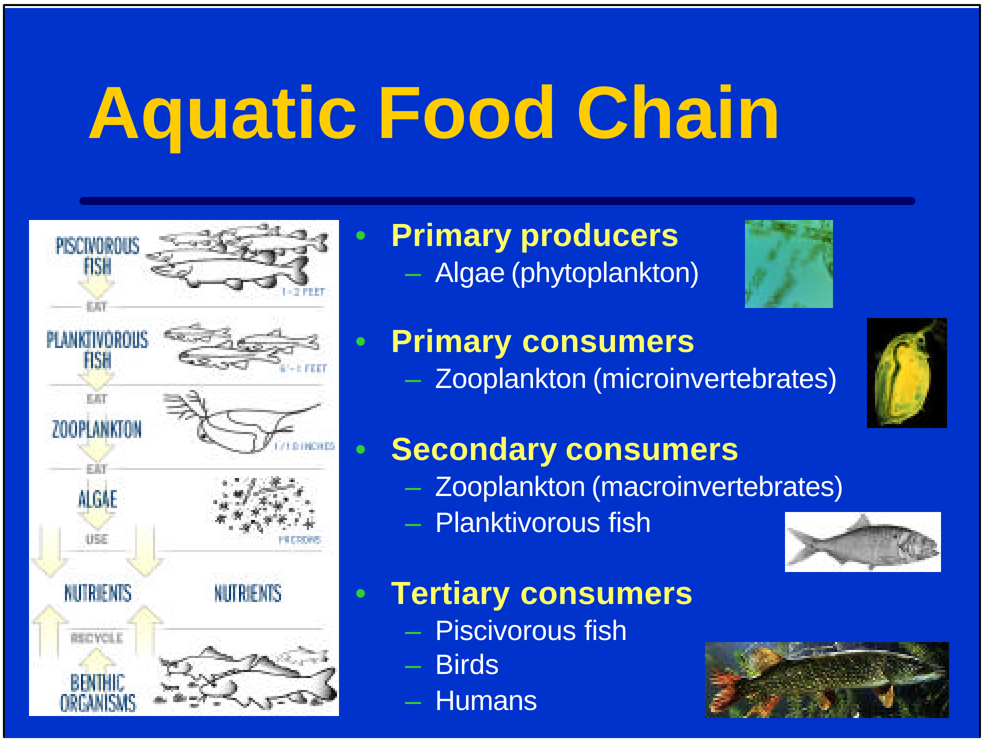
- Natural water systems have well-defined boundaries– the shoreline, the sides of the basin, the surface water, and the bottom sediment. Gradations of light, oxygen, and temperature profoundly influence the type of organisms that inhabit these boundaries.
- The ***littoral zone***, or shallow water zone, is the zone where light penetrates to the bottom. This area is occupied by rooted plants such as water lilies, rushes, and sedges. The higher plants in the littoral zone, in addition to being a food source and a substrate for algae and ***invertebrates***, provide a habitat for fish and other organisms that is very different from the open water environment.
- The ***limnetic zone***, or open water zone, extends from the surface of the water to the bottom of the ***euphotic zone*** (zone in which photosynthesis occurs). Dominating the limnetic zone are ***microinvertebrates*** (e.g., phytoplankton and zooplankton), ***macroinvertebrates*** (e.g., crayfish), fish populations, amphibians and reptiles.
- The bottom sediment, known as the ***benthic zone***, has a surface layer abundant with organisms. This upper layer of sediments may be mixed by the activity of the benthic organisms that live there, often to a depth of 2-5 centimeters (several inches) in rich organic sediments. Most of the organisms in the benthic zone are invertebrates, such as Dipteran insect larvae (midges, mosquitoes, black flies) or small crustaceans. The productivity of this zone largely depends on the organic content of the sediment, the amount of physical structure, and in some cases on the rate of fish predation. Sandy substrates contain relatively little organic matter (food) for organisms and poor protection from predatory fish. Higher plant growth is typically sparse in sandy sediment, because the sand is unstable and nutrient deficient. A rocky bottom has a high diversity of potential habitats offering protection (refuge) from predators, substrate for attached algae (periphyton on rocks), and pockets of organic “ooze” (food). A flat mucky bottom offers abundant food for benthic organisms but is less protected and may have a lower diversity of structural habitats, unless it is colonized by higher plants.



- The United States Geological Survey (USGS) has more than 7,000 monitoring stations that measure stream levels, streamflow (discharge), reservoir and lake levels, surface-water quality, and rainfall. Hydrologists use this data to determine whether the streams are experiencing drought, normal, or flood conditions.
- Hydrologic statistics are used to determine if current rain events (or lack of) will cause flooding or droughts. The two most common hydrologic statistics are the seven-consecutive day flow recurring over a ten-year period (7Q10) and the one day flow recurring over a three-year period (1Q3). Hydrologists compare daily stream flow to these statistical events and can determine whether a flood or drought will occur.
- In the analysis of floods, droughts, available water supply, water table recharge, and other surface water and ground water hydrology, both the river ***discharge*** (flow rate) and ***stage*** (depth) must be measured continuously. The river discharge and stage change constantly due to the variability in precipitation and temperature.
- A graph of a river discharge or stage is called a ***hydrograph***. The discharge hydrograph is not measured directly, but is inferred from the stage hydrograph. As the river rises and falls, the float or gage moves with the water level and the motion of the float is recorded. This data is used in the stage hydrograph. To construct a discharge hydrograph, the river velocity must be measured. A current meter attached to a wading rod or suspended from a cable, depending on the depth and discharge of the river, is used to measure the velocity.
- During and after rainfall and snowmelt events, water moves through the catchment to the stream channel and the discharge increases. The resulting peak in the hydrograph is termed a flood, regardless of whether the river actually leaves its banks. Background discharge between floods is termed base flow and is supplied by inflow of groundwater.



- The subsurface is divided into zones or layers based on hydrologic properties.
  - The ***vadose zone*** is part of the ***unsaturated zone***. The unsaturated zone is directly below the surface and contains some water. In the unsaturated zone, water and air fill the voids between soil or rock particles.
  - Deeper in the ground is the ***zone of saturation***. In the zone of saturation, the subsurface is completely saturated with water.
  - The point where the unsaturated zone meets the zone of saturation is known as the ***water table***.
- Water table levels fluctuate naturally throughout the year based on seasonal variations in precipitation. In addition, the depth to the water table varies. For example, in southern Louisiana, the water table may be as shallow as 2 inches below the surface, while in the Mojave Desert the water table may be 600 feet below the surface.
- The saturated zone may form an aquifer. An ***aquifer*** is a geologic formation that contains water in quantities sufficient to support a well or spring.
- The inter-relationship between ground water and surface water means that contamination can migrate between the two.



- A food chain is an arrangement of the organisms of an ecological community according to the order of predation in which each uses the next (usually lower) member as a food source. Trophic levels correspond to the different levels or steps in the food chain.
- ***Phytoplankton***, microscopic floating plants, mainly algae, that live suspended in the ***water column***, are the main source of food for most organisms. Algae constitute the main group of ***primary producers (first trophic level)*** (organisms that convert CO_2 to biomass using sunlight for energy, a process called photosynthesis).
- Zooplankton, mostly ***microinvertebrates*** that swim about in open water, are ***primary consumers (second trophic level)***. They graze on algae (phytoplankton), bacteria, and detritus (partially decayed organic material). Some zooplankton are ***macroinvertebrates***, and can be seen with the naked eye. Consumers can live and grow in all zones, although the lack of oxygen may limit their abundance in bottom waters and sediments.
- ***Secondary consumers (third trophic level)*** include plankton-eating fish or predaceous zooplankton that eat other zooplankton.
- ***Tertiary consumers (fourth trophic level)*** include larger consumers such as adult northern pike, ospreys and humans that eat fish.

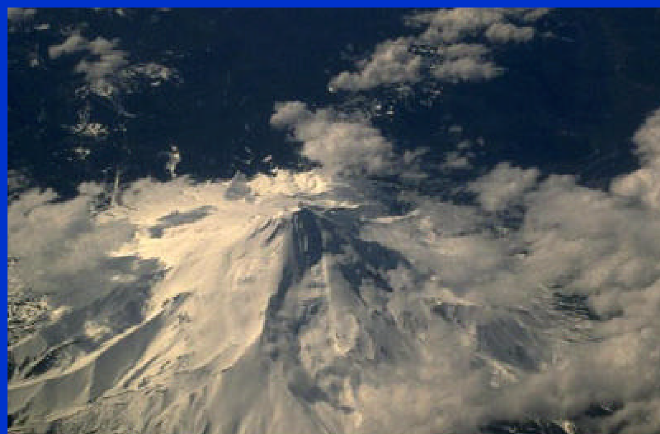
The Concept of Change

- Sources of change
  - Natural causes
  - Manmade causes

Without proper restoration, mining can have severe impacts upon stream hydrology, morphology, biota and water quality.

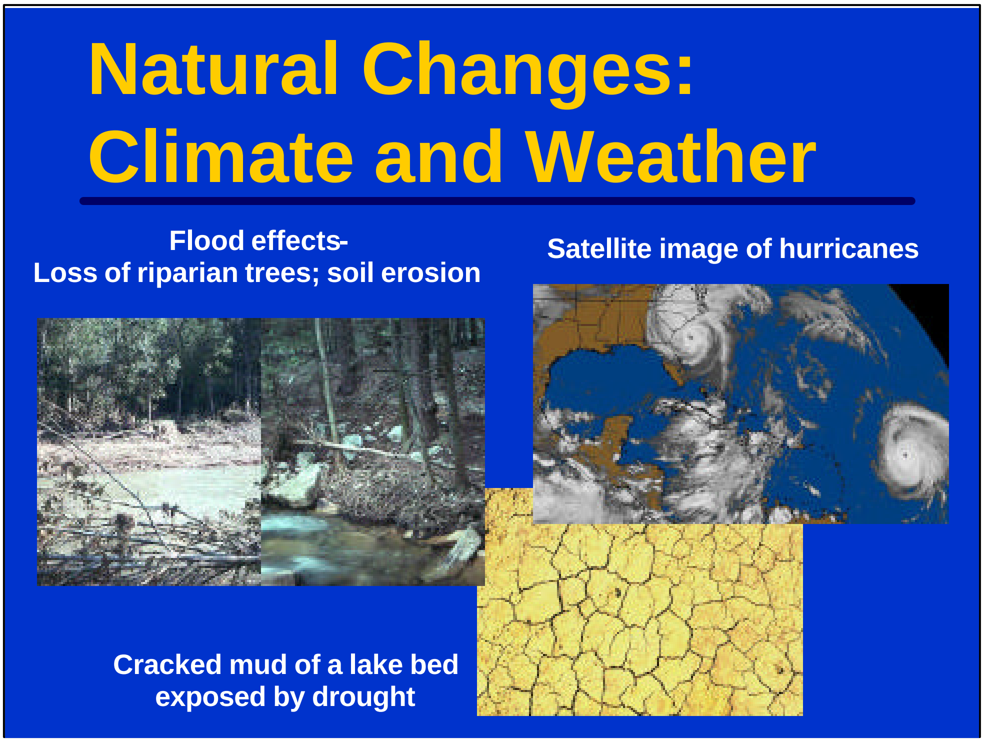
- Change is both ***unavoidable and essential*** in a watershed, as plant and animal communities are continually altered in response to environmental changes. Different types of changes are usually described in terms of the ***sources*** or causes of change and the ***effects*** they bring about.
- Environmental changes almost always benefit some species to the detriment of others. Changes that markedly decrease populations of favored wildlife or plant species, or limit a watershed's ability to provide resources for human communities (e.g., drinking water, food, recreation), are widely seen as degradation, especially by affected people.
- Changes that produce significant, widespread, or long-term degradation are changes of concern. These types of changes alter the ways in which ecosystems organize, remain functional, and evolve over time, and threaten the abilities of ecological communities to recover and persist following period disturbance.
- Changes of concern are most often related to manmade causes or to the high-magnitude, cumulative effects of manmade plus natural causes acting together.
- It is important to note that many manmade changes of concern are avoidable, and considerable progress has been made in understanding human influence on change and how to manage our impacts.
- This next set of slides looks at examples of natural and manmade sources of change and the effects of change on natural water systems.

Natural Changes: Geological Activity



Mount Hood, Oregon

- During the Pleistocene era (12,000 to 15,000 years ago), ***glaciers*** slowly moved across the landscape forming the majority of lakes we find in North America. Ice dams would fail catastrophically when they began to float, causing massive floods. The estimated discharge from the greatest flood is approximately 9 cubic miles of water per hour, which is 450 times the maximum recorded for the Mississippi River (sources: Alt and Hyndman 1995).
  - On a much smaller scale, ice is an important change agent in many northern watersheds. Ice jam-induced floods in early spring can significantly modify channels and floodplains and the plant and animal communities that inhabit them.
- ***Tectonic activity*** has formed lakes and altered the course of rivers over long periods of geologic time and over short events associated with earthquakes. For example, irregular tilting of fault blocks created depressions such as the basin where Lake Tahoe is located. In contrast, the New Madrid Earthquake of 1811 formed several of the lake basins of Tennessee and Missouri and reversed the flow of the Mississippi River for a short time before it cut a new course to the sea. Earthquakes can also cause landslides that dam rivers or alter their courses (source: Hutchinson 1957).
- ***Volcanoes*** can alter watersheds with tremendous force over very short periods of time. New lake basins are formed while old ones fill in. Changes in local topography create new routes for water that result in mountain streams where they had not existed before. On Mt. St. Helens, the eruption of 1980 caused huge mudslides that formed a dam resulting in a much-enlarged Spirit Lake. Extensive areas of upland forest were burned or buried, and numerous nearby streams and rivers suffered fish kills due to heavy sediment loads in the water.



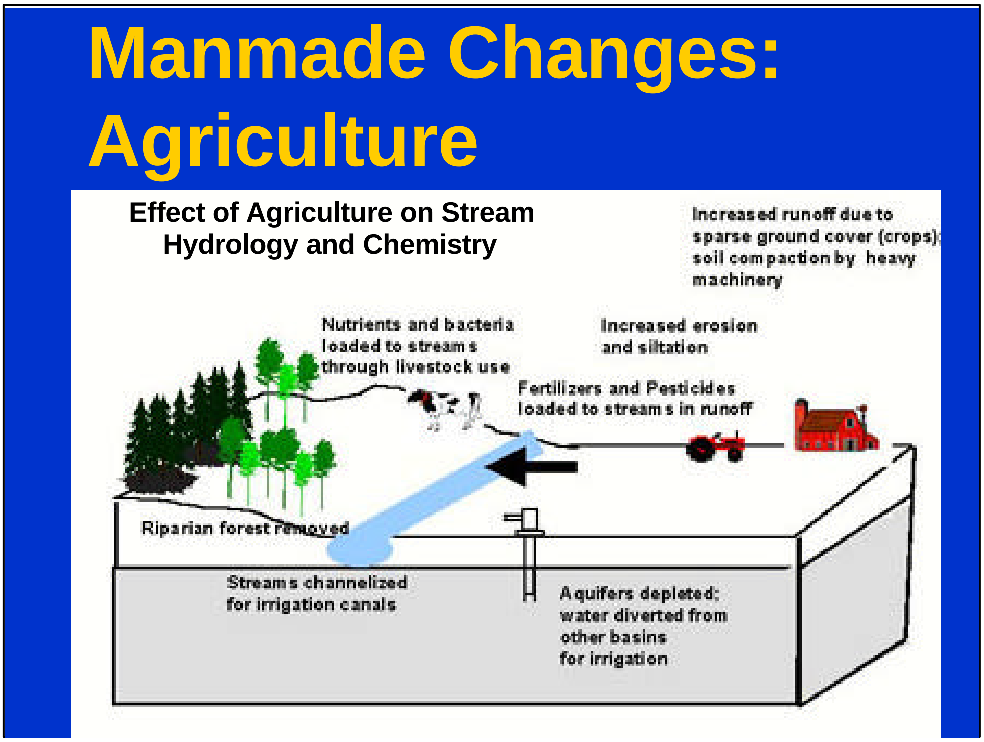
- In rivers and streams, ***floods*** are critical for several reasons. They redistribute organic material and living organisms downstream and create an opportunity for exchange of sediment and nutrients with the floodplains. However, during intense floods, entirely new channels can form, riparian forests can be displaced, and major landslides and debris torrents can be triggered, leading to a more extensive ecological recolonization and recovery period.
- In addition to the obvious adverse effect of significantly reducing water volume or flow, ***drought*** can have a major impact on water chemistry by altering the relative contribution of ground water versus surface water. For species of birds and amphibians, the disappearance of seasonal water bodies due to drought can have a detrimental effect on the population due to temporary elimination of breeding or feeding grounds. Beyond affect the water body and its aquatic organisms, drought also can affect upland areas of watersheds. For example, crop failures from sustained droughts can eventually lead to abandonment of agricultural land uses and communities or cause the loss of huge volumes of topsoil no longer stabilized by crops or natural vegetation (“dust bowl”).
  - However, drought can also have a beneficial effect. Periodic drawdowns restore health to ecosystems, resulting in the betterment of fish populations. By exposing lake bottoms to air and sunlight, sediments, algae, vegetation and organic soils seed germination and growth of beneficial plant life is fostered. Healthy plant diversity brought on by the drought is the basis of a propitious food chain.
- ***Wind*** can affect water quality and aquatic ecosystem health, for example, by adding significant quantities of windblown soil to the water. Wind events are often responsible for transporting debris and organisms to different areas of a water body.
- Although there is strong evidence of human-induced ***climate change*** effects, climate change has always been a natural change agent over long periods of time. Over the life span of long-lived species, climate may change to the extent that subsequent generations will not reproduce effectively in protected areas.

Natural Changes: Other

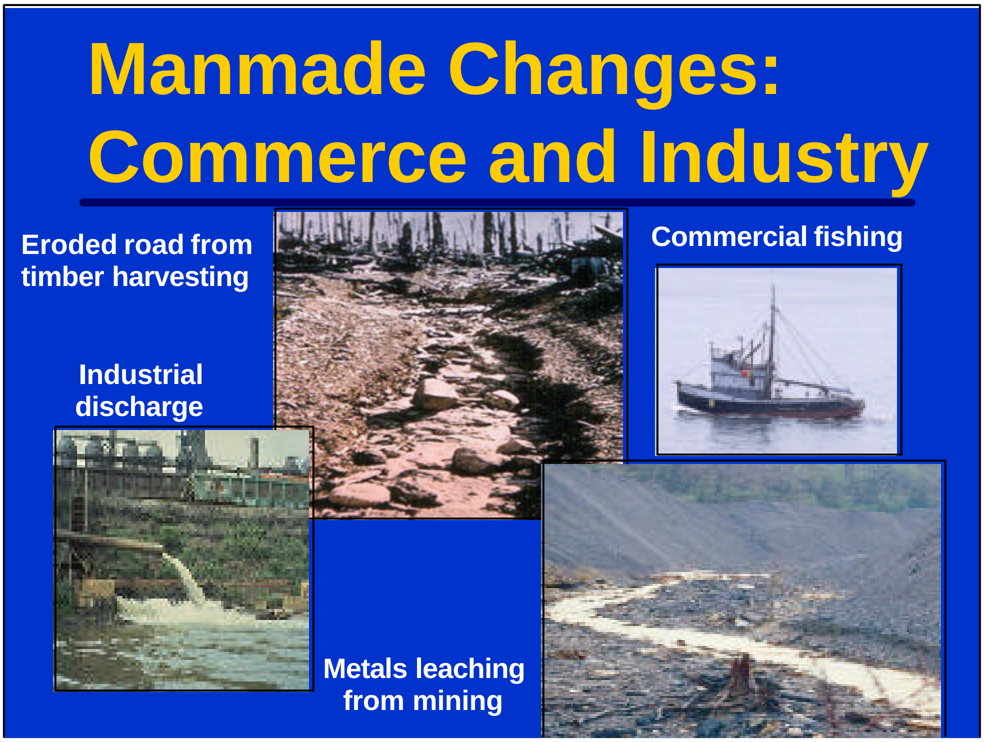
Sediment eroded from a wilderness area upstream enters a California river

Fire

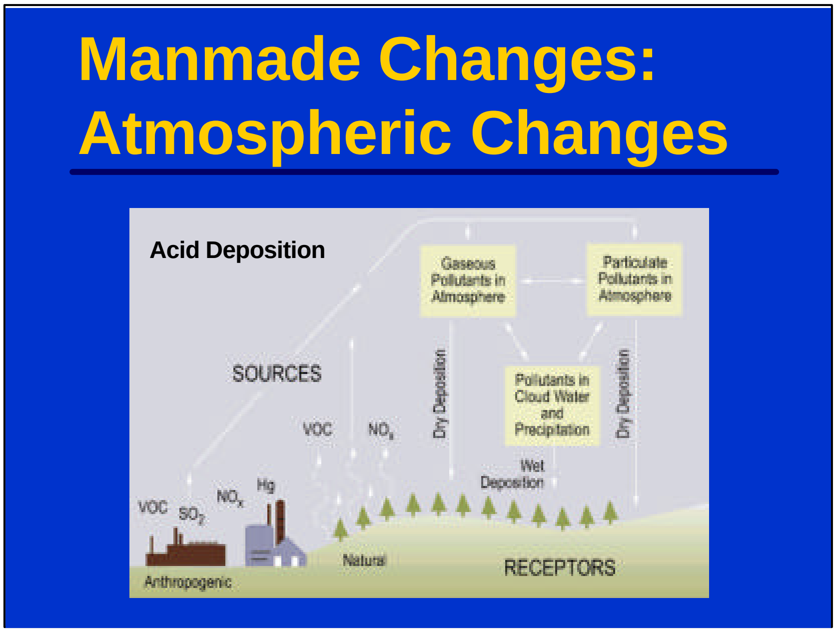
- ***Fire***'s effects on water quality can vary widely. (FISRWG, 1998). ***Fire*** is an important component of forest ecology, and its effects on water quality can vary widely. Very intense fire can volatilize important nutrients needed by terrestrial plans, but less intense fires can ***mobilize nutrients*** for rapid uptake and growth. Fire increases the availability of soil nutrients, resulting in ***increased biodiversity***. However, large-scale fires in a watershed with steep slopes can accelerate erosion and runoff, raise water temperatures due to removal of riparian cover, and leave a watershed more vulnerable to other disturbances for a period of years. Recognizing this, forest managers in the U.S. national parks have adopted a fire management policy that combines a let-burn approach with active monitoring and prescribed burns.
- Despite the fact that ***erosion*** can dramatically affect water quality, sediment erosion, ***transport and redeposition are among the most essential natural processes*** occurring in watersheds. Although sediment may enter a river from adjacent banks, most is transported from upstream sources. In most parts of a watershed erosion, transport and deposition do not occur at constant rates, but are highly active during events such as floods, windstorms, ice scour, and seasonal or drought-induced exposure of soil.



- ***Agricultural practices*** can affect watersheds and ground water through several different means. Changes of concern result from streamside vegetation removal and soil tillage, runoff from application of fertilizers and pesticides, grazing practices that shift grassland vegetation to dominance by inedible species, and irrigation practices that dewater streams to levels that harm aquatic communities.
- Under agricultural development, ***crops*** generally represent ***sparser ground cover than indigenous vegetation***, allowing ***greater erosion and soil loss***. Lands are plowed and smoothed to created planting surfaces, while use of heavy machinery for tilling and threshing compacts soil.
- Streams through agricultural lands typically have ***high levels of dissolved nutrients*** (e.g., nitrogen and phosphorus) due to runoff of fertilizer and loss of forest cover. A typical result in agricultural streams and lakes is ***increased primary production (i.e., eutrophication)*** and ***depletion of dissolved oxygen*** as excess organic matter decomposes. Organochlorine compounds associated with pesticide use are also found in some agricultural waters. Although pesticide spraying occurs for a limited period, some compounds persist long enough in soil to load continually throughout the year. In many cases, toxic effects may persist for several years after pesticide use has stopped.
- ***Livestock grazing and large-scale animal feeding operations*** can cause degraded water quality. Cattle that frequent riparian zones can increase sediment and debris in streams. Estimates indicate that the ***quantity of animal waste is 13 times greater than human sanitary waste*** generation in the United States. Livestock waste can be introduced to the environment through direct discharges, open feedlots, land application, animal housing, and pastures.
- ***Irrigation*** of agricultural fields can also have dramatic impacts on watershed hydrology through ***diversion and detention of running waters and overutilization of ground water reserves***.

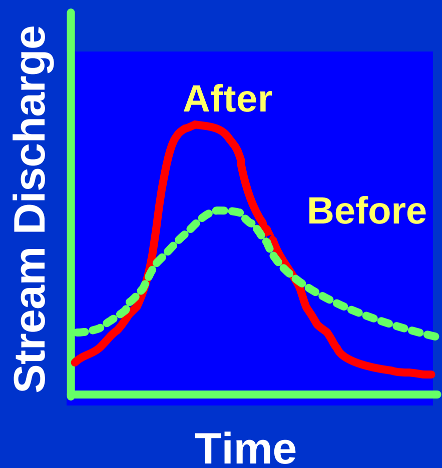


- Many watershed effects of ***timber harvesting and silviculture*** (cultivation of forest trees) are similar to agriculture's effects. Aquatic impacts such as altered runoff and streamflow, increased sedimentation, and addition of nutrients can result from silvicultural operations. Loss of mature vegetative cover leads to decreased evapotranspiration and correspondingly increased peak flows. These effects are compounded by road construction which creates bare surfaces and compacts soil, resulting in decreased infiltration and increased surface runoff. Increased surface runoff , along with fewer trees for bank stabilization, generally causes increased erosion and siltation, leading to elevated and more variable water temperature and increased turbidity which generally impair habitat for a number of fish and invertebrate species.
- ***Mining and mineral development*** result in a series of environmental changes that may occur over several decades. Mining operations remove significant amounts of soil and rock. Even if chemically inert, erosion of exposed overburden can result in excessive siltation affecting stream and lake ecosystems. After being removed, waste rock is usually stored above ground in freestanding piles. These rocks can react with water and oxygen to form sulfuric acid leachate (acid mine drainage) that drains to streams, lakes and ground water. Finely-ground tailings (residues from mining and milling) usually contain residues of toxic organic chemicals used in ore concentrators. The tailings make metals that were formerly bound up in solid rock accessible to water, increasing the potential for heavy metal contamination in aquatic communities.
- Commercial ***harvesting of fish and wildlife*** may have significant effects on community composition and trophic (food web) interactions, where harvest pressures have resulted in a gradual shift from large, long-lived, high trophic level species to smaller, shorter-lived, lower trophic level species. Placing a moratorium on certain species, such as the striped bass in the Chesapeake Bay, has been used successfully to increase populations of overharvested fish. This is an example of the kind of sacrifice in natural resource use that can become necessary, in part, due to changes of concern in a watershed.
- Examples abound of the damage that can be caused by ***industrial discharges*** to water bodies. Effects to aquatic life and water quality from wastewater discharges containing kepone to PCBs to hot water discharges from power generation are numerous and well-documented.



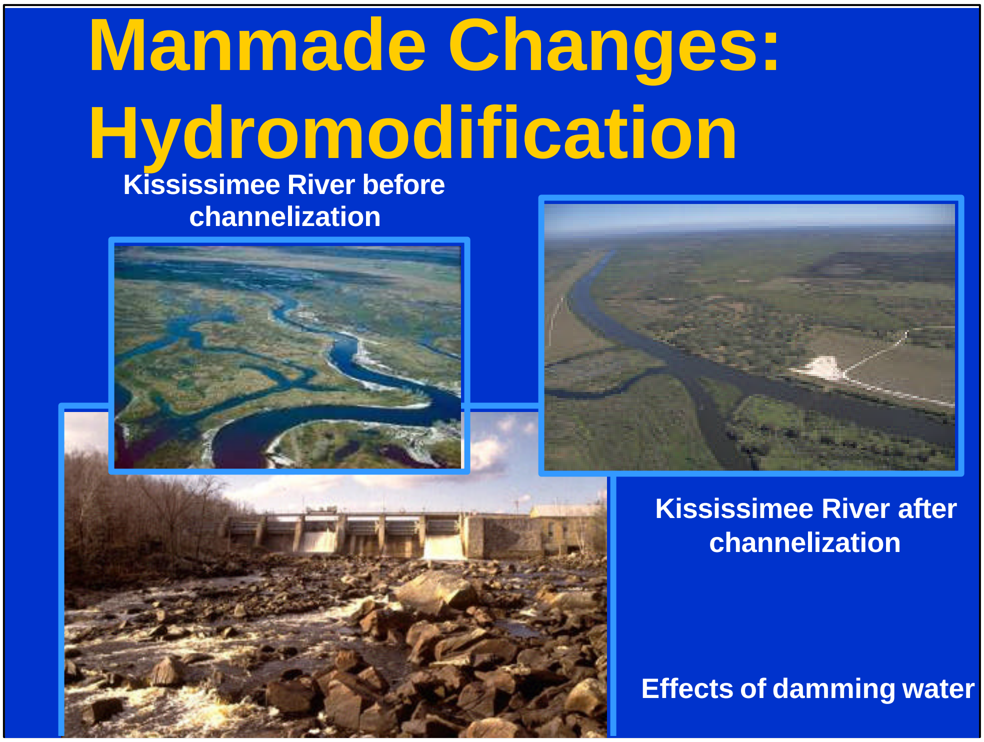
- Another manmade source of change is ***acid deposition***--both ***wet and dry***. Wet deposition refers to acidic rain, fog, and snow. Dry deposition refers to acidic gases and particles. About half of the acidity in the atmosphere falls back to earth through dry deposition. The wind blows these acidic particles and gases onto buildings, cars, homes, and trees. Dry deposited gases and particles can also be washed from trees and other surfaces by rainstorms. When that happens, the runoff water adds those acids to the acid rain, making the combination more acidic than the falling rain alone.
- The ecological effects of acid rain are most clearly seen in aquatic environments. Acid rain flows to streams, lakes, and marshes after falling on forests, fields, buildings, and roads. Acid rain also falls directly on aquatic habitats. Acid rain causes a cascade of effects that harm or kill individual fish, reduce fish population numbers, completely eliminate fish species from a waterbody, and decrease biodiversity.
  - As acid rain flows through soils in a watershed, ***aluminum is released from soils*** into the lakes and streams in the watershed. Both low pH and increased aluminum levels are directly toxic to fish. In addition they cause chronic stress that may not kill individual fish, but leads to lower body weight and smaller size and makes fish less able to compete for food and habitat.
  - The ***impact of nitrogen*** on surface waters is also critical. Nitrogen is an important factor in causing eutrophication (oxygen depletion) of water bodies. The symptoms of eutrophication include blooms of algae (both toxic and nontoxic), declines in the health of fish and shellfish, loss of seagrass and coral reefs, and ecological changes in food webs.
- A major difference between natural and ***manmade climate change*** is the rate at which it occurs. Over the last century, the average surface temperature of the earth has warmed by approximately 1° F. Current predictions indicate that we can expect an increase of 3.5°F over the next century with the continued release of carbon dioxide into the atmosphere.
- When the air temperature increases just 1° F, the air can hold 6 percent more water. This warming trend tends to speed up the exchange of water among oceans, land, and atmosphere. Longer droughts punctuated by heavy bursts of rain and flash flooding are a consequence. These effects can determine the water supply available to plans and the hydrologic regime of streams and rivers. Species composition of upland plant communities will also undergo major changes.

Manmade Changes: Land Use and Urbanization

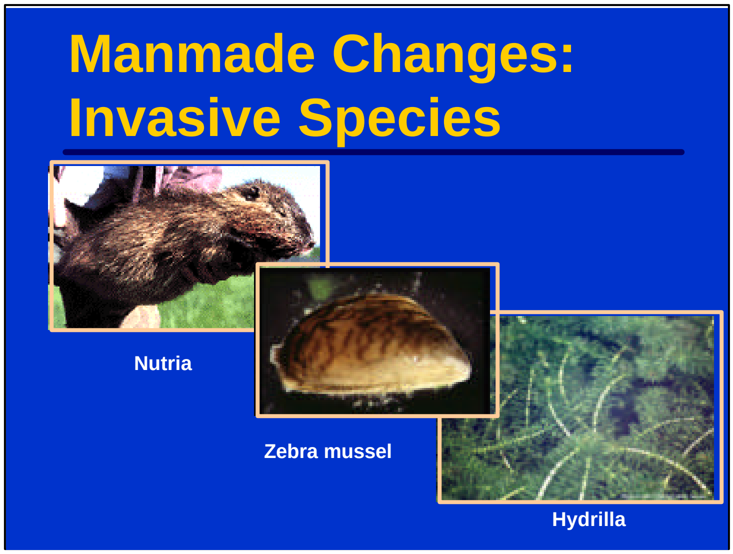


Aerial view of Washington, D.C.

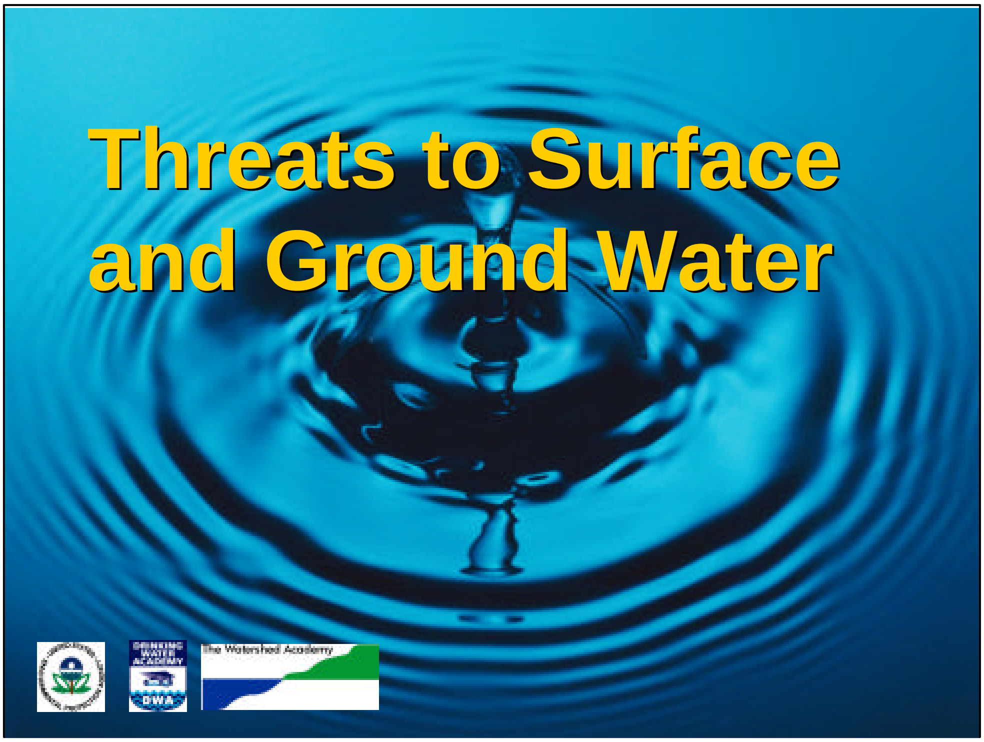
- Land uses have the potential for major effects on water quality. ***Storm water runoff*** from many different land uses, such as farms, paved surfaces (e.g., parking lots), construction sites, animal feeding operations, lawns and golf courses, deposit many contaminants in surface water: pesticides, fertilizers and herbicides; dirt, oil and debris; pathogens; and chemicals.
- ***Urbanization*** often has more severe hydrologic effects than timber harvesting or agriculture, as watershed vegetation is replaced with impervious surfaces such as paved roads and parking lots. This increases surface runoff and earlier and higher peak flows following storms. Frequent high flows tend to enlarge urban streams, resulting in increased turbidity, channeling and erosion. These physical impacts of urbanization are compounded by contaminant inputs from point sources (e.g., sewage, industrial effluents) or nonpoint sources (litter and other debris in storm runoff).
- This generalized hydrograph shows the effects of increasing impervious surface in a watershed–quicker and higher peak flows after a storm event versus the situation prior to development. Base flows decrease as well. Research done by the Center for Watershed Protection and other organizations generally indicates that water quality and stream habitat start to decline when impervious surfaces cover as little as 10 percent of a watershed.
- The effects of urbanization also affect water supply. As urban growth increases, water must be pumped from increasingly great distances to meet sewage and drinking water needs. This may require aqueducts and canals and other diversions and impoundments that can cause widespread hydrologic and ecological changes.
- Wetlands provide another example of how changing land uses can affect water quality. Wetlands have suffered major acreage losses to human development. Some have been degraded by excessive deposits of nutrients and sediment from construction and farming. Severe flooding and nutrient deposition to downstream waters have often followed wetland destruction and degradation.

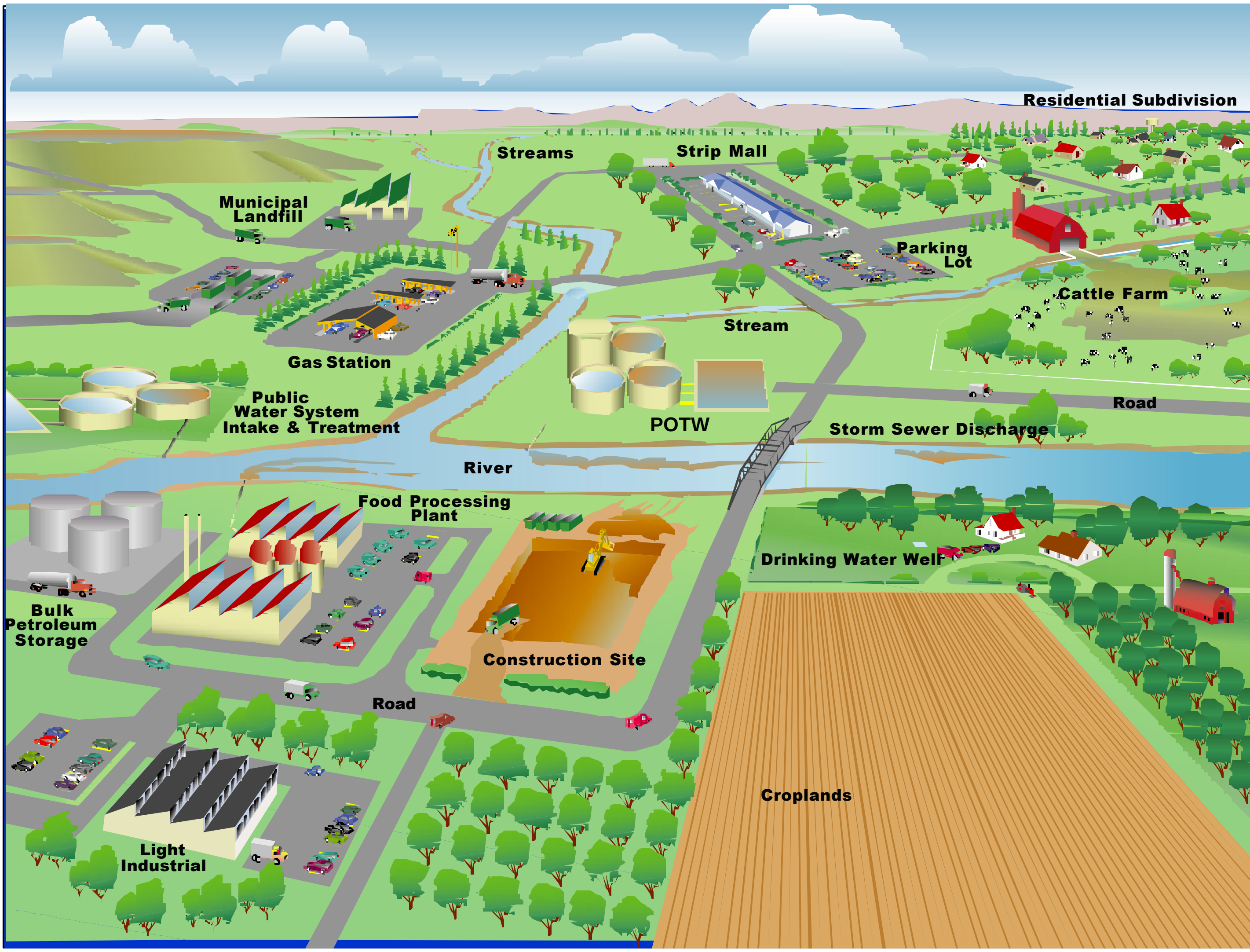


- Approximately 3.5 million river miles were once free-flowing across North America. Now, 500,000 to 600,000 (14-17 percent) are now ***behind dams***. None of the 15 largest rivers in the U.S. is unaffected by human impoundments and diversions. In many cases, impoundment and water withdrawal result in reduced flow, increased baseflow variation, altered temperatures, reduced ability to transport sediment, and destruction of habitats.
- Downstream temperature can also experience significant changes in response to dam operation. Reservoirs in temperate latitudes typically stratify as lakes do, with a warm water surface layer and cold, dense depths. Dams that release surface water tend to increase annual temperature variation, whereas dams that release deep water tend to decrease annual temperature variation. Substantial biological consequences can result from altered temperature regimes and related changes in dissolved oxygen. Dams also act as sediment traps that limit downstream sediment delivery, with mixed effects on downstream habitat. In the arid Southwest, for example, non-native trout fisheries are now present at the base of dams that release cold, clear water into river channels that were once filled with warm, sediment-laden water.
- ***Stream channelization*** usually refers to the practice of straightening and smoothing a section of a river bed. Bulldozers and other heavy equipment are used to straighten the river into a uniform channel, in the hope that the water will flow through the channel more quickly. Usually these projects are conceived in a "mitigation panic" after a local episode of flooding. While the channelization may remove the water more quickly from a channelized area, it simply dumps that same water at the end of the channel creating a flooding problem for the downstream residents.
- In addition to the ***increased threat of flooding downstream***, there is also an ***increase in erosion*** downstream. In a natural stream bed the energy of the falling water is dissipated slowly by turbulence and friction with the streambed. In a channelized stream the water emerges with much of this energy still present in the form of kinetic energy. When this water hits the downstream section it expends that energy as an increase in erosion.
- The actual channelization process kills everything in the stream and the stream habitat that remains after the project is unsuitable for most forms of aquatic life. There are few eddies where fish can rest and hide; there is little suitable habitat for stream insects.



- ***Invasive species*** are defined as plant or animal species that are non-native (or alien) to the ecosystem under consideration **and** whose introduction causes or is likely to cause economic or environmental harm or harm to human health (Executive Order 13112). Invasive species can successfully invade any terrestrial or aquatic ecosystem, and may enter through a wide variety of introduction mechanisms. Human activities, both intentional and non-intentional, are the chief cause of invasive species introductions.
- In some cases, introduced species do not prosper because they lack adaptations to the local environments, but in many cases they outcompete native species through prolific reproductive strategies and a lack of natural predators. Establishment of exotic species often results in significant changes in food webs and community composition.
- Invasive species' effects on water resources can be direct, as in the case of many aquatic nuisance species, or indirect, as in terrestrial species that change water tables, runoff dynamics, fire frequency, and other watershed attributes that in turn can alter water body condition. Beyond the dramatic estimate of $138 billion for yearly economic impacts and control costs, impacts to ecosystems and their beneficial services are estimated to be several times more than this total. Examples include:
  - ***Nutria,*** released in southern coastal marshes for fur production, often completely strip marsh vegetation cover and have destroyed over 100,000 acres of salt marsh in Louisiana that will probably revert to open water. Nutria also outcompete muskrats, whose pelt quality is far superior. This species has recently spread to the Chesapeake Bay.
  - ***Hydrilla***, results in an array of ecosystem disruptions. Changes often begin with its invasion of deep, dark waters where most plants can not grow. It has been shown to alter the physical and chemical characteristics of lakes. Hydrilla seriously affects water flow and water use. Infestations in the Mobile Delta are reducing flow in small tidal streams and creating a backwater habitat. Its heavy growth commonly obstructs boating, swimming and fishing in lakes and rivers and blocks the withdrawal of water used for power generation and agricultural irrigation.
  - ***Zebra mussels*** were transported in ballast waters of large ships arriving from Europe. The mussels clog engines, municipal water intakes, and cooling systems as well as concentrating toxins and altering food chains, reduce fish populations, damage spawning areas, smother native mussel beds, and cause ***taste and odor problems in drinking water***, causing over $ 3.1 billion in economic impacts alone during the past 10 years.


Threats to Surface
and Ground Water
DRINKING WATER ACADEMY
DWA
The Watershed Academy

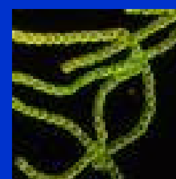


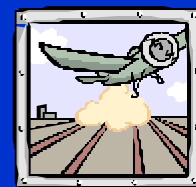
Class Discussion:

- How do this community's activities affect or put stress on the physical, chemical and biological condition of its surface and ground water?
- What types of contaminants would these activities contribute to surface and ground water?
- What effects might this have on the community as a whole and on individuals who live, work, and visit there?

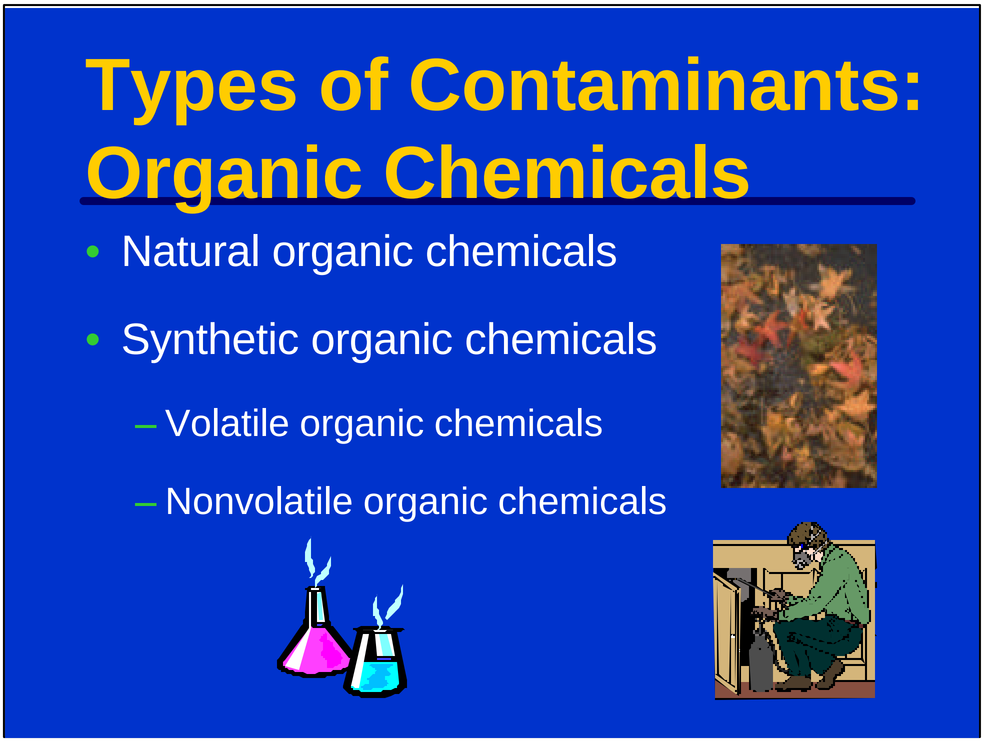
Contaminants and Pollutants

- Chemicals
  - Organic
  - Inorganic
  - Disinfection byproducts
- Biological organisms
  - Pathogens
  - Invasive species
- Physical
  - Heat





- All of the changes we have been discussing can cause chemical and biological contaminants, which cause adverse health and ecological effects, to enter a body of water.
- Contaminants may cause adverse health and ecological effects directly (through exposure to water) or may act indirectly. For example, freon released into the atmosphere does not directly influence health; instead it reduces the thickness of the protective ozone layer of the atmosphere, consequently increasing the risks of skin cancer.
- Note that disinfection byproducts are, scientifically, a subset of organic chemicals. They are listed separately here because under SDWA they are treated as a separate class of contaminant. The implications of this will be discussed later in this course.

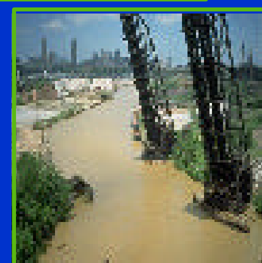


- ***Natural organic chemicals*** enter the water from trees and other plants that border water bodies, from agricultural runoff, and from aquatic life. The presence of a sufficient concentration of dissolved oxygen is critical to maintaining the aquatic life and the aesthetic quality of streams and lakes. However, the principal cause of oxygen depletion is the decomposition of organic matter, especially dead plant material. As aquatic or other vegetation in the water decomposes, either as a result of herbicide use or natural die-off, the process uses oxygen. During the warm summer months, decomposition may use what little dissolved oxygen is in the water, resulting in an insufficient amount for fish.
- ***Synthetic organic chemicals*** (SOCs) are man-made compounds that are used for a variety of industrial and agricultural purposes. Adverse health effects from exposure to synthetic organic chemicals include damage to the nervous system and kidneys, and cancer risks. SOCs can be divided into two groups: non-volatile SOCs and volatile organic chemicals.
  - ***Non-volatile synthetic organic chemicals*** (SOCs) include pesticides, insecticides and herbicides, such as atrazine, alachlor and 2,4,D. Atrazine has the potential to cause weight loss; cardiovascular damage; retinal and some muscle degeneration; and cancer. Alachlor can cause eye, liver, kidney, or spleen problems; anemia; and an increased risk of cancer. Herbicides can harm aquatic plants.
  - ***Volatile organic chemicals*** (VOCs) are manmade compounds used for a variety of industrial and manufacturing purposes. Among the most common VOCs are chemicals used as solvents and degreasers such as benzene and toluene, insulators and conductors (PCBs), and dry-cleaning agents. VOCs have the potential to cause chromosome aberrations, cancer, nervous system disorders, and liver and kidney damage.

Types of Contaminants: Inorganic Chemicals

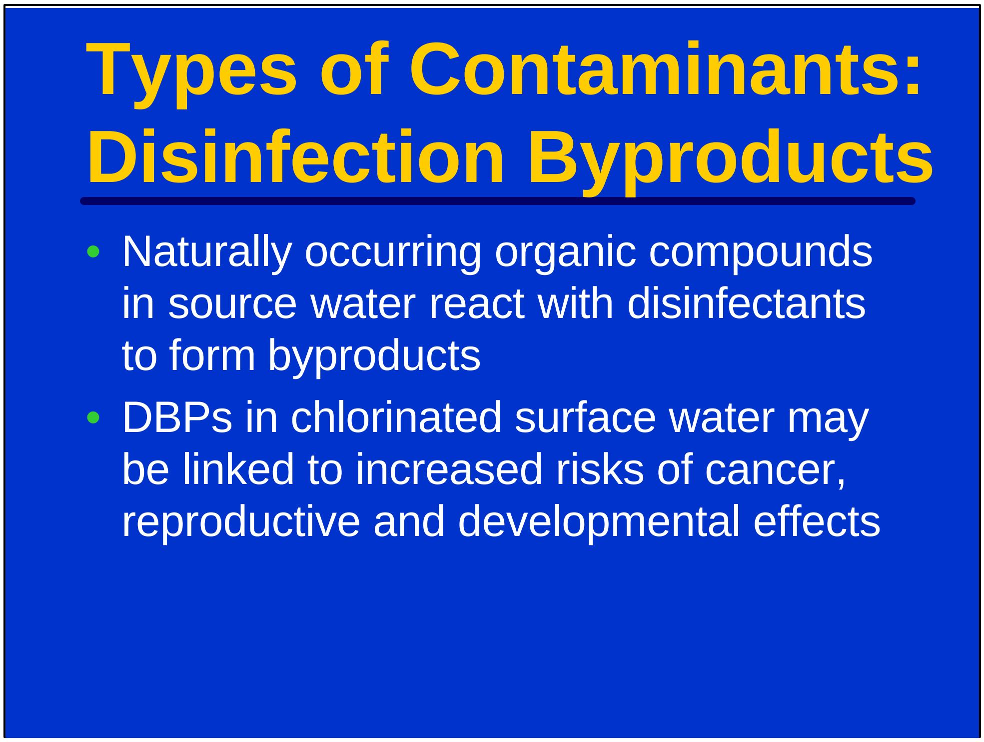
- Metals and minerals
- Radionuclides
- Nutrients (nitrogen and phosphorus)
- Sediments

Fertilizer spreader



Sediment loading after rain

- ***Inorganic chemicals*** may appear as elements or compounds in water supplies. They include metals or minerals such as arsenic, lead, and copper. They may occur naturally in the geology or they may be caused by mining, industry or agricultural activities. It is common to have trace amounts of many inorganic chemicals in water supplies. In larger amounts, however, inorganic chemicals can be dangerous and can cause a variety of damaging effects to the liver, kidney, nervous system, circulatory system, gastrointestinal system, bones, and skin, depending upon the chemicals and level of exposure. Pregnant women and infants are especially susceptible to harm from inorganic chemicals.
- Exposure to ***radionuclides*** results in an increased risk of cancer. Certain elements accumulate in specific organs. For example, radium accumulates in the bones and iodine accumulates in the thyroid. For uranium, there is also the potential for kidney damage. Many water sources have very low levels of naturally-occurring radioactivity – low enough not to be considered a public health concern. However, contamination of water from manmade materials also occurs. These radioactive materials are used in various ways in the production of commercial products (such as television and smoke detectors), electricity, nuclear weapons, and in nuclear medicine in therapy and diagnosis. Releases of manmade radionuclides to the environment are primarily the result of improper waste storage, leaks or transportation accidents.
- ***Nitrogen*** (N) and ***phosphorus*** (P) are widely used in fertilizers. Nitrogen is used to promote green, leafy, vegetative growth in plants. Phosphorus promotes root growth, root branching, stem growth, flowering, fruiting, seed formation, and maturation. Excessive phosphorus from runoff and erosion can fertilize surface waters. In this process, called eutrophication, algae multiply rapidly when fertilized by phosphorus. These algae cloud the water making it difficult for larger submerged aquatic vegetation (SAV) to get enough light. The SAV may die, reducing available habitat of aquatic animals. When the algae themselves eventually die they decompose. During decomposition dissolved oxygen is removed from the water. Lowered oxygen levels make it difficult for other aquatic organisms to survive.
- Suspended ***sediments*** can clog the gills of fish, while increased fines in spawning beds impede water flow and hamper oxygenation of incubating salmon eggs. Increased sedimentation may also have indirect or interactive effects, such as increased contaminant loadings.



- Disinfection of drinking water is one of the major public health advances of the 20th century. Disinfection is a major factor in reducing the typhoid and cholera epidemics that were common 100 years ago in U.S. cities.
- While disinfectants are effective in controlling many microorganisms, certain disinfectants (notably chlorine) react with natural organic and inorganic matter in source water and distribution systems to form ***disinfection byproducts (DBPs)***. A large portion of the U.S. population is potentially exposed to DBPs through its drinking water. More than 240 million people in the United States are served by public water systems that apply a disinfectant to water to protect against microbial contaminants.
- Results from toxicology studies have shown several DBPs (e.g., bromodichloromethane, bromoform, chloroform, dichloroacetic acid, and bromate) to be carcinogenic in laboratory animals. Other DBPs (e.g., chlorite, bromodichloromethane, and certain haloacetic acids) have also been shown to cause adverse reproductive or developmental effects in laboratory animals.
- Epidemiological and toxicological studies involving DBPs have provided indications that these substances may have a variety of adverse effects across the spectrum of reproductive and developmental toxicity: early-term miscarriage; still birth; low birth weight; premature babies; and congenital birth defects.

Types of Contaminants: Pathogens

- Viruses and bacteria
- Parasites, protozoa, algae and cysts

CDC. *E. coli* 0157:H7

- ***Pathogens*** are microorganisms that can cause disease in other organisms or in humans, animals and plants. They may be bacteria, viruses, or parasites and are found in sewage, in runoff from animal farms or rural areas populated with domestic and/or wild animals, and in water used for drinking and swimming. Fish and shellfish contaminated by pathogens, or the contaminated water itself, can cause serious illnesses.
  - A ***virus*** is the smallest form of microorganism capable of causing disease. A virus of fecal origin that is infectious to humans by waterborne transmission is of special concern for drinking water regulators. Many different waterborne viruses can cause gastroenteritis, including Norwalk virus, and a group of Norwalk-like viruses.
  - ***Bacteria*** are microscopic living organisms usually consisting of a single cell. Waterborne disease-causing bacteria include *E. coli* and *Shigella*.
  - ***Protozoa*** or ***parasites*** are also single cell organisms. Examples include G*iardia lamblia* and *Cryptosporidium*.
- Pathogens may cause effects after acute (short-term) exposures.

Types of Contaminants: Pathogens

Giardia

Cryptosporidium

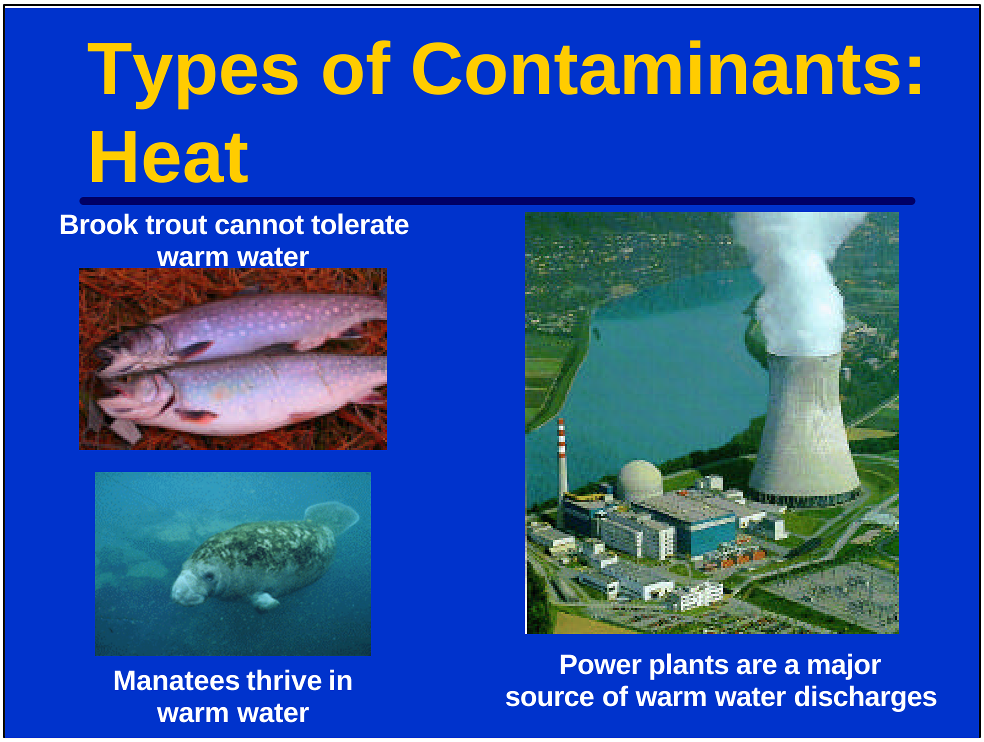
- *Giardia lamblia* was only recognized as a human pathogen capable of causing waterborne disease outbreaks in the late 1970s. Its occurrence in relatively pristine water as well as waste water treatment plant effluent called into question water system definitions of “pristine” water sources. During the past 15 years, *Giardia lamblia* has become recognized as one of the most common causes of waterborne disease in humans in the United States. This parasite is found in every region of the U.S. and throughout the world. In 1995, outbreaks in Alaska and New York were caused by *Giardia*. The outbreak of giardiasis in Alaska affected 10 people, and was associated with untreated surface water. The outbreak in New York affected an estimated 1,449 people, and was associated with surface water that was both chlorinated and filtered. The symptoms of giardiasis include diarrhea, bloating, excessive gas, and malaise.
- *Cryptosporidium* (often called “crypto”), which cannot be seen without a very powerful microscope, is so small that over 10,000 of them would fit on the period at the end of this sentence. The infectious dose for crypto is less than 10 organisms and, presumably, one organism can initiate an infection. As late as 1976 it was not known to cause disease in humans. In 1993, more than 400,000 people in Milwaukee, Wisconsin, became ill with diarrhea after drinking water contaminated with the parasite. Since then attention was focused on determining and reducing the risk of cryptosporidiosis from public water supplies. Crypto is commonly found in lakes and rivers and is highly resistant to disinfection. People with severely weakened immune systems are likely to have more severe and more persistent symptoms than healthy individuals.

Types of Contaminants: Pathogens

Fish kill

Red Tide

- Harmful ***algae*** are microscopic, single-celled plants that live in the sea. Most species of algae or phytoplankton are not harmful and serve as the energy producers at the base of the food web. Occasionally, the algae grow very fast or “bloom” and accumulate into dense, visible patches near the surface of the water. “Red Tide” is a common name for such a phenomenon where certain phytoplankton species contain pigments that give the water a reddish appearance.
- Whether toxic or noxious algal species dominate a bloom or alternatively, occur at low but harmful levels within a phytoplankton community, their presence often affects other trophic levels, resulting in mass ecosystem dysfunction, public health risk, and enormous economic losses. The devastating effects of such blooms are frequently seen on the west coast of Florida where the proliferation of the toxic protozoan *Gymnodinium breve* can result in massive fish kills, closure of shellfish beds, and skin and respiratory irritation to humans at the seashore.
- ***Pfiesteria*** is a single-celled organism living in rivers and coastal waters. Toxic forms of Pfiesteria release a powerful neurotoxin that stuns fish. The toxins cause open, bleeding sores to develop and fish begin to die. A fish kill may continue for hours or days. Sometimes fish are found sick and with sores, but not dead. The Pfiesteria toxin is short-lived in water.
- ***Dermo disease*** is caused by a single-celled protozoan parasite, *Perkinsus marinus*, that affects the eastern oyster. It is not known to be harmful to humans. Dermo is transmitted from oyster to oyster. Natural infections are most often caused by parasites released from the disintegration of dead oysters. Infective stages, free in the water column, are ingested by uninfected oysters and invade the stomach and intestine. Waterborne stages of the parasite may spread the disease over long distances. Transmission may also occur by scavengers feeding on infected dead oysters or by parasitic snails. Dermo disease caused extensive oyster mortalities in the Gulf of Mexico in the late 1940s. Later, it caused chronic and occasionally massive mortalities in the Chesapeake Bay. Since 1990, Dermo has been detected in Delaware Bay, Long Island Sound, Massachusetts, Rhode Island and Maine.



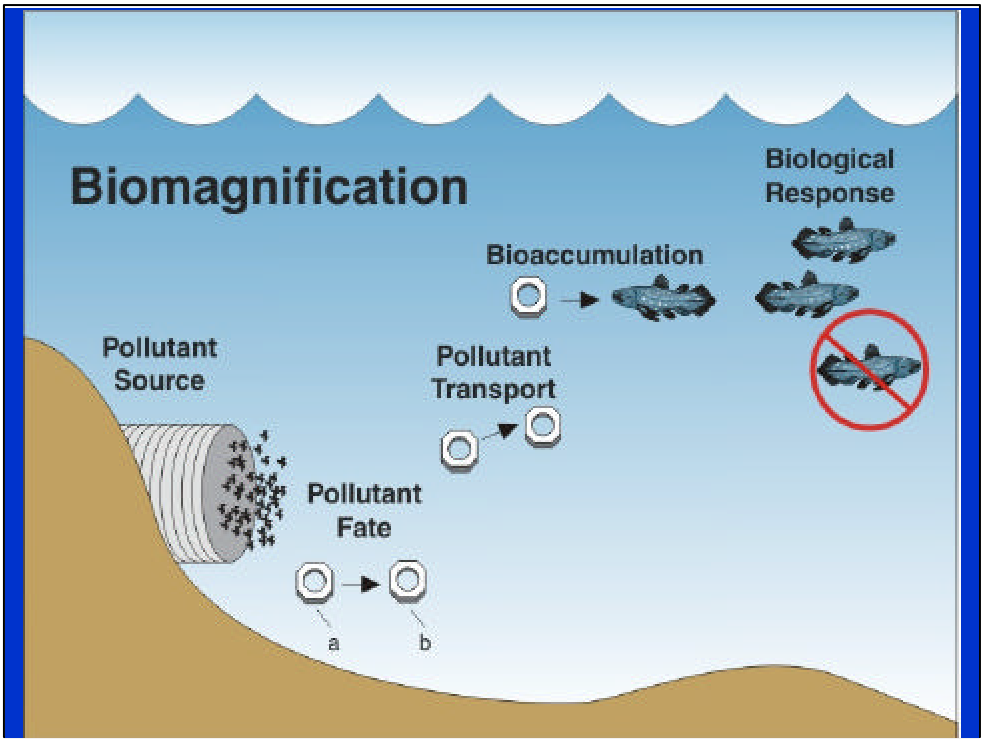
- ***Heat, or thermal pollution***, can be a deadly water pollutant. An important relationship exists between the amount of dissolved oxygen in water and its temperature. The warmer the water, the less dissolved oxygen.
- Thermal pollution can be natural, such as in hot springs or shallow ponds during summer months, or it can be human-made, when water used to cool power plants or other industrial equipment is discharged back into streams.
- The amount of oxygen in water affects the life it can support. Some sport fish, such as trout, need cold water with high levels of dissolved oxygen and cannot live in warm water. Other nongame fish like carp and suckers thrive in warm water and can take over habitats from other fish if waters become too warm. This can result in greatly reduced diversity of fish species important for the environmental health of the stream.
- Thermal pollution has been such a problem that most States have passed laws requiring power plants and industries to cool water before releasing it back into streams.

Effects of Contamination

- Adverse health effects
- Ecological effects and costs
- Economic costs
- Aesthetic costs

Health Effects: Pathways of Exposure

- Human routes
  - Drinking water
  - Foods
  - Body contact
- Aquatic organisms
  - Respiration
  - Food
- Semi-aquatic wildlife
  - Food

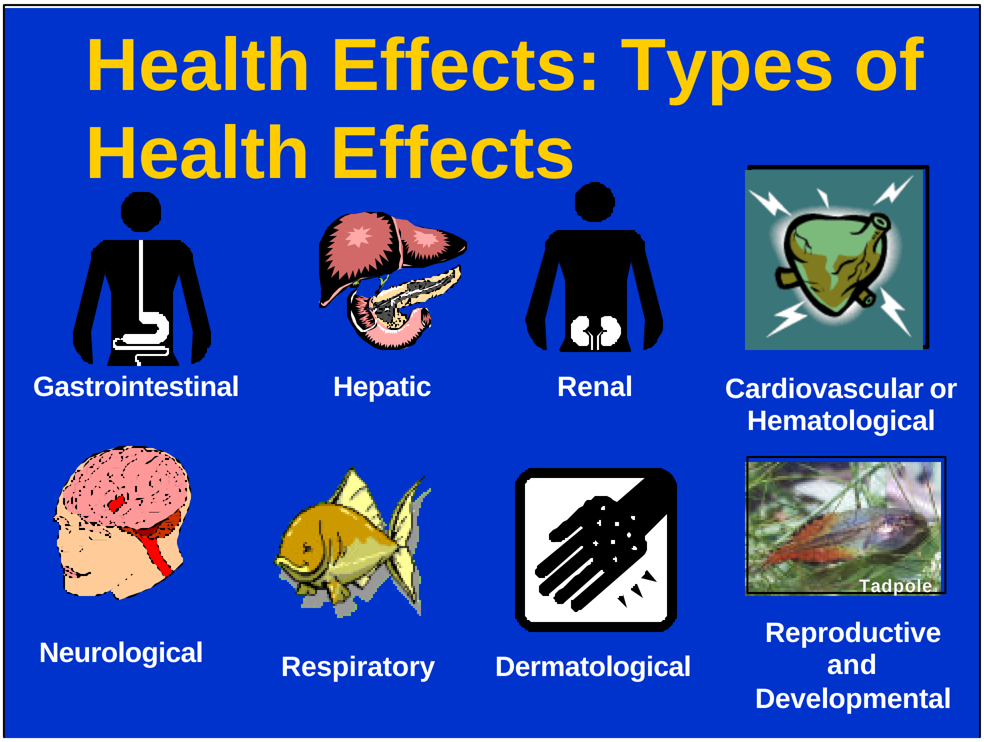


- Certain pollutants, such as ***PCBs, dioxin, and mercury***, accumulate in the tissues of aquatic organisms as one moves up the food chain. Consequently, these pollutants may occur in the water column at very low levels, perhaps undetectable with current analytic techniques, but would be found in the tissue of higher-order predators at greater concentrations, and which may present significant risk to humans and/or other organisms that consume these predators.
- Contaminated sediments affect small creatures such as worms, crustaceans, and insect larvae that inhabit the bottom of a water body in what is known as the ***benthic environment***. Some kinds of toxic sediments kill benthic organisms, reducing the food available to larger animals such as fish.
- Some contaminants in the sediment are taken up by benthic organisms in a process called ***bioaccumulation***. When larger animals feed on these contaminated organisms, the toxins are taken into their bodies, moving up the food chain in increasing concentrations in a process known as ***biomagnification***. As a result, fish and shellfish, waterfowl, and freshwater and marine mammals, as well as benthic organisms, are affected by contaminated sediments.
- When contaminants bioaccumulate in trout, salmon, ducks, and other food sources, they pose a threat to human health. In 1998, fish consumption advisories were issued for more than 2,506 bodies of water in the United States. Possible long-term effects of eating contaminated fish include cancer and neurological defects.
- Contaminated sediments do not always remain at the bottom of a water body. Anything that stirs up the water, such as a storm or a boat's propeller, can resuspend some sediments. Resuspension may mean that all of the animals in the water, and not just the bottom-dwelling organisms, will be directly exposed to toxic contaminants.

Health Effects: Temporal Aspects

- Duration
  - Short term (acute)
  - Long term (chronic)
- Pattern
  - Constant or continuous
  - Intermittent
    - Frequent
    - Infrequent

- The effects a pollutant has on various life forms depends no only on its potency and the exposure pathway,but also on the temporal pattern of exposure.
- ***Short term exposure*** (minutes to hours) is referred to as ***acute***. ***Longer term exposure*** (days, weeks, months, years) is referred to as ***chronic***.
- The constancy of exposure is also a factor in the how exposure affects an organism. For instance, the effects of seven days of exposure may differ depending on whether the exposure was on seven consecutive days or seven days spread over a month, a year, or several years.



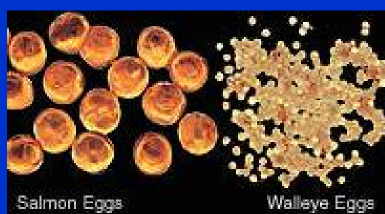
- Contaminants in drinking water can adversely affect or cause disease in humans, other animals and plants. These effects are known as toxic effects.
- Below are general categories of toxicity, based on the organs or systems in the body affected:
  - Gastrointestinal: affecting the stomach and intestines.
  - Hepatic: affecting the liver.
  - Renal: affecting the kidneys.
  - Cardiovascular or hematological: affecting the heart, circulatory system or blood.
  - Neurological: affecting the brain, spinal cord, and nervous system. In non-human animals, behavior changes can result in lower reproductive success and increased susceptibility to predation.
  - Respiratory: affecting the nose, trachea, and lungs or the breathing apparatus of aquatic organisms.
  - Dermatological: affecting the skin and eyes.
  - Reproductive or developmental: affecting the ovaries or testes, or causing lower fertility, birth defects or miscarriages. This includes contaminants with genotoxic effects; i.e., capable of altering Deoxyribonucleic acid (DNA). This can have mutagenic effects (changes in the genetic materials causing cells to misfunction) which can cause cancer or birth defects (teratogens).

Health Effects: Carcinogenicity

- Category I compounds are carcinogens
- Category II compounds exhibit carcinogenic as well as noncarcinogenic endpoints
- Category III compounds are noncarcinogenic

- Substances that cause cancer are known as ***carcinogens***. Compounds are classified as carcinogens based on evidence gathered in studies. EPA has a three-category approach to classifying compounds as carcinogenic, based on evidence of carcinogenicity, pharmacokinetics (the absorption, distribution, metabolism, and excretion of substances from the body), potency, and exposure:
    - ***Category I*** compounds are carcinogens.
    - ***Category II*** compounds exhibit limited evidence of carcinogenic endpoints and also exhibit noncarcinogenic endpoints.
    - ***Category III*** compounds are noncarcinogenic.

Health Effects: Sensitive Sub-Populations and Life Stage

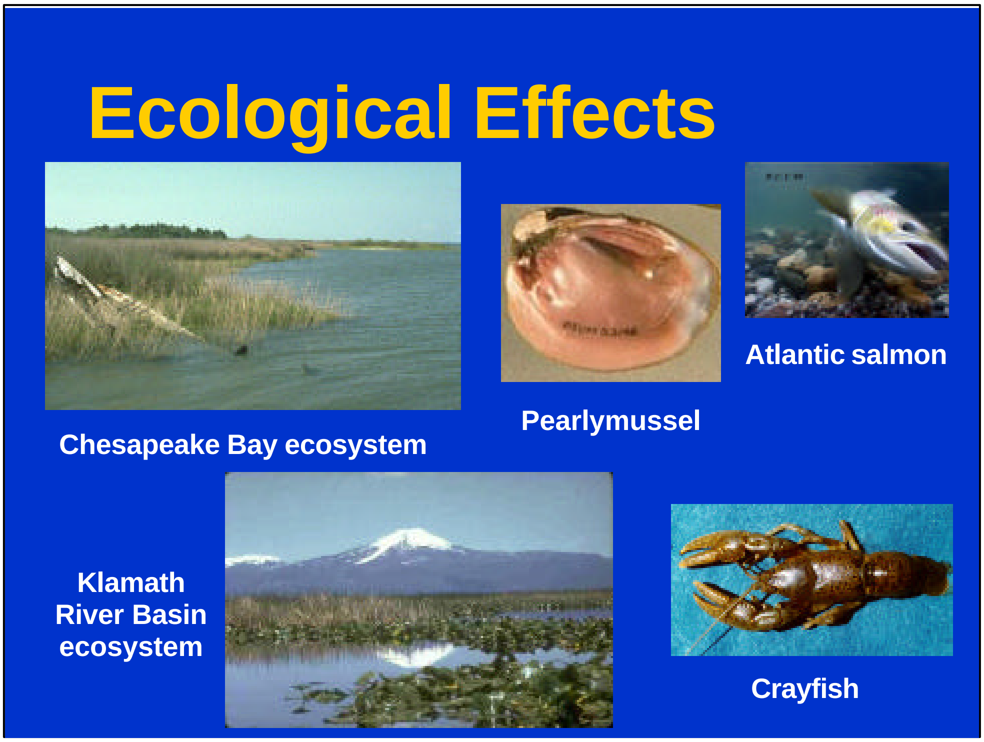


- Some organisms may be more susceptible to the effects of contaminants. If evidence shows that a specific subpopulation is more sensitive to a contaminant than the population at large, then safe exposure levels are based on that population. If no such scientific evidence exists, pollution standards are based on the group with the highest exposure level. Some commonly identified sensitive subpopulations include infants and children, the elderly, pregnant and lactating women, and immuno-compromised individuals.
    - The bodies and organ systems of newborn and young animals and plants process chemicals differently than those of full-grown organisms. In humans, organs develop throughout childhood and some are not completely mature until puberty. This affects the body's ability to recover from damage due to environmental toxins and affects the rates at which our bodies metabolize, distribute, or excrete substances. Embryos and larval stages of aquatic and semiaquatic animals and plants are similarly affected.
    - Individuals who are severely immuno-compromised (that is, have weakened immune systems) may include those who are infected with HIV/AIDS, cancer and transplant patients taking immunosuppressive drugs, and people born with weakened immune systems.
- Critical exposure period effects may involve a single or multiple exposures but they occur during specific periods that relate to the risk. Internal biological changes associated with aging, state of health, and genetic predisposition can increase the potential for elderly people to be more sensitive to environmental conditions than other members of the population. Metabolic, excretory, and other bodily functions change as people age due to changes in organ function and reduction in lean body mass and the percentage of body fat, and total body water. Other examples include reproductive and developmental effects, such as the effect of lead on children's neural development.
- Typically, a species is not hypersensitive to all kinds of contaminants. One species may be sensitive to "x," but not "y," and another species may have the opposite sensitivity.

- Due to unique social and demographic characteristics, various segments of the population may experience exposures different from those of the general population, which, in many cases, may be greater. Therefore, risk assessors must consider those ***groups who are exposed to contaminants at the highest level***. Individuals who consume certain foods or drink water in amounts significantly higher or in greater proportion than the general population will be exposed to associated contaminants at higher levels.

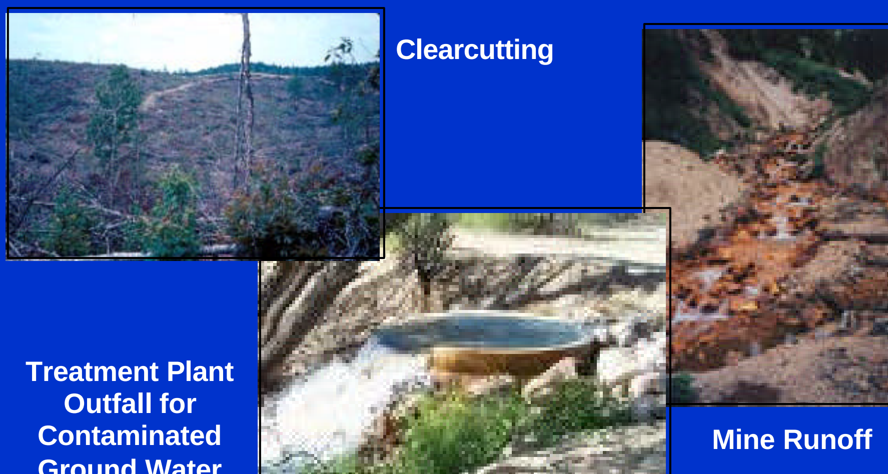
- Subsistence fishermen, for example, consume fish at a much higher rate than the general population. Thus, they receive higher exposures to contaminants that bioaccumulate in fish. Native Americans, Alaska Natives, and low income Southeast Asians are the major population subgroups participating in subsistence fishing.

- Some people may drink more than the two liters of water per day that the general population averages, potentially exposing them to contaminants in drinking water at higher levels. For example, athletes and people who work at strenuous occupations may drink more water than the general population.



- ***Ecosystems*** provide services that help sustain and fulfill human life. These services maintain biodiversity and produce ***ecosystem goods***, such as seafood, wild game, forage, timber, biomass fuels, natural fibers, and many pharmaceuticals, industrial products, and their precursors. The harvest and trade of these goods represent important parts of the human economy.
- Ecosystems are being impaired and destroyed by a wide variety of human activities. Foremost among the immediate threats are the continuing ***destruction of natural habitats*** and the ***invasion of non-native species*** that often accompanies such disruption. The most irreversible of human impacts on ecosystems is the ***loss of native biodiversity***.
- As a whole, organisms that depend on freshwater ecosystems are in grave condition. The *1997 Species Report Card*, released by The Nature Conservancy in cooperation with the state Natural Heritage Network, found that:
  - 67 percent of U.S. freshwater mussels are vulnerable to extinction or are already extinct; more than one in ten mussels may have become extinct during this century along.
  - 303 fish species—37 percent of the U.S. freshwater fish fauna—are at risk of extinction; 17 species have already gone extinct, most in this century.
  - 51 percent of U.S. crayfishes are imperiled or vulnerable.
  - 40 percent of amphibians are imperiled or vulnerable.
  - At least 106 major populations of salmon and steelhead trout on the West Coast have been totally destroyed, and an additional 214 salmon, steelhead trout, and sea-run cutthroat trout stocks are at risk of extinction.
- Freshwater species as a whole are much more imperiled than terrestrial species. Although extinction is a natural process, scientists report that current extinction rates are on the order of 1,000 times normal rates. More than 300 freshwater species are listed or proposed for listing under the Endangered Species Act.

Costs of Contamination: Ecological Costs



- Quantifying ecological costs in monetary terms can be controversial and difficult. However, these impacts do need to be considered and can often be quantified in nonmonetary terms. Healthy ecosystems have a direct link to quality of life.
- Contaminated water can destroy aquatic habitats as well as terrestrial habitats. Wildlife that live in these affected habitats will have to move to a new location where clean water is available or perish, if a suitable habitat cannot be found.
- The toxic microbe Pfiesteria piscicida has killed millions of fish in North Carolina since 1995 and tens of thousands of fish in Maryland in 1997. Losses to the U.S. seafood and tourism industries from Pfiesteria are estimated at $1 billion. Maryland alone suffered $43 million in canning and fishing losses in a single year. North Carolina is now spending millions of dollars for watershed restoration in an effort to control potential outbreaks in the future.
- Mining in the western United States has contaminated stream reaches in the headwaters of more than 40 percent of the watersheds in the West. EPA is spending $30,000 per day to treat contaminated mine drainage at the Summitville Mine in Colorado, which will cost an estimated $170 million to clean up. Remediation of the half-million abandoned mines in 32 States may cost up to $35 billion or more.

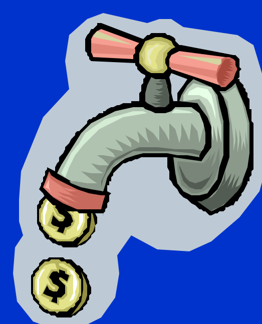
Costs of Contamination: Economic Costs

- Decrease in real estate values
- Loss of business development
  - Decrease in jobs
  - Decrease in tax revenues
- Decrease in agricultural productivity
- Decrease in recreation and tourism revenue

- Preventing water contamination can also help to ***increase or maintain real estate values***. A waterfront view is a prime selling feature. For example, one subdivision in Boulder, Colorado, reported a 30 percent premium price for lots located alongside a wetland. The same holds true for commercial property: in Laurel, Maryland, office space fronting a wet pond system rents at a premium of $100 to $200 per month. Conversely, a survey by the Freshwater Foundation found that five Minnesota cities collectively lost over $8 million in tax revenues because of real estate devaluation as a result of ground water pollution.
- Protecting water bodies may also ***prevent the loss of existing or potential tax revenues and jobs*** when businesses refuse to locate or remain near places with known or suspected problems or when water bodies can no longer support commercial activity. Nationally, the dollar value of fish and shellfish that are landed and sold in the 50 states by U.S. fishermen is nearly $3.7 billion. Overfishing and habitat loss has resulted in declining populations for many fish species.
- Water is a necessity for ensuring ***agricultural productivity***. American farmers produce food and fiber products worth $197 billion a year, and the sale of livestock and poultry produce another $98 billion. The agricultural industry uses 63 percent of all ground water withdrawals, mostly for irrigation.
- In 1995 the U.S. Geological Survey estimated that ***manufacturing*** companies used more than 9 trillion gallons of fresh water per year. In many cases, water supports production purposes and is treated and returned to a surface or ground water source. Proper treatment of this returned water is essential to ensure a continued supply.
- Travel, tourism and recreation provided more than 6.8 million jobs and generated annual sales in 1996 of more than $450 billion. Water-related recreation and tourism account for a large part of this. Americans spend $44 billion annually in coastal tourism; sales of kayaks and canoes in 1996 alone exceeded $99 million. If sport fishing were incorporated as a single business, it would rank approximately 24th on the Fortune 500. Preventing contamination of a water body that serves as a major scenic or tourist attraction can ***safeguard local tourism and recreation revenues***. For example, the annual value of tourism and recreation in the Keuka Lake watershed in upstate New York was conservatively estimated at $15 million in 1996.

Costs of Contamination: Drinking Water Treatment Costs

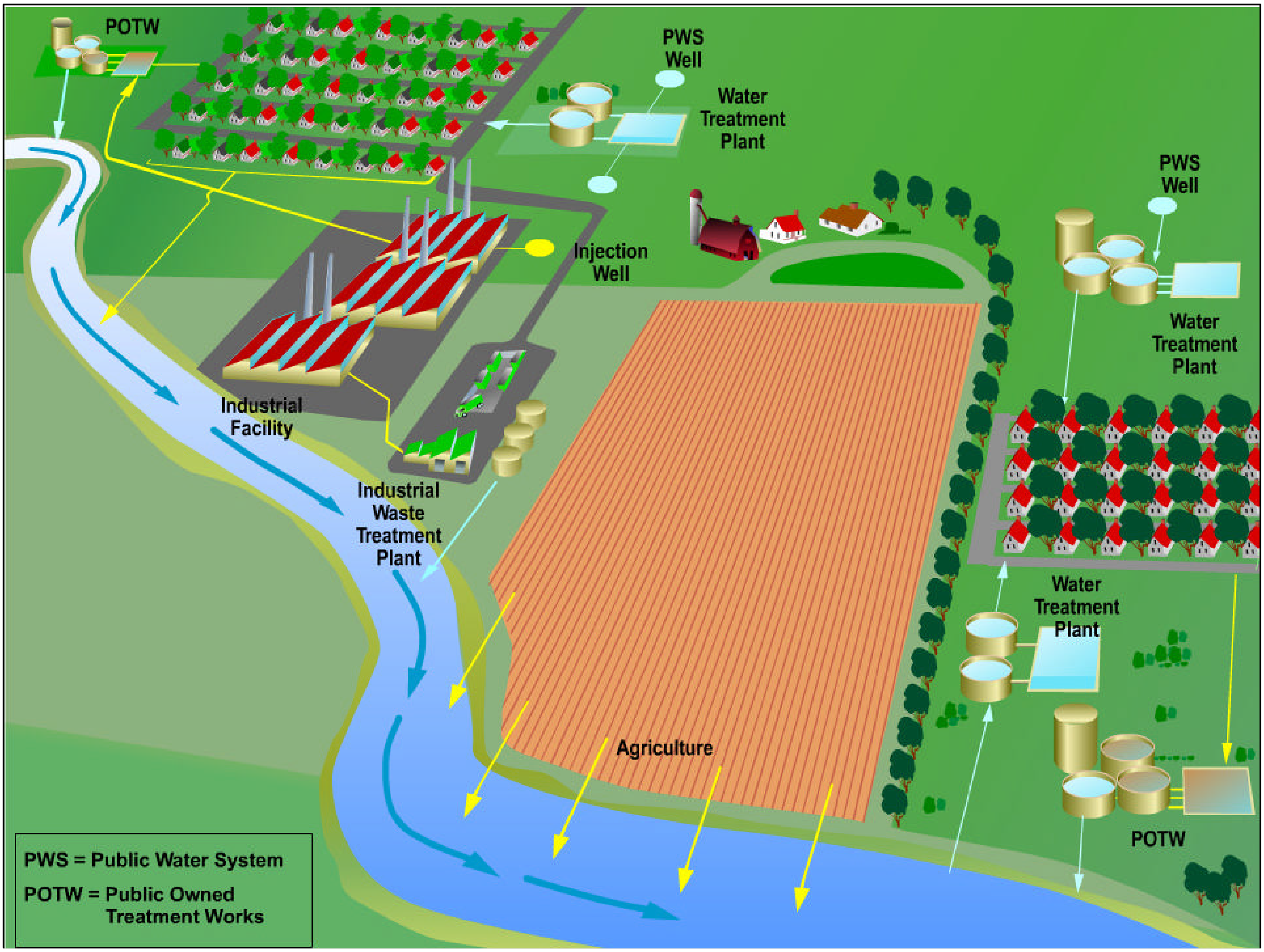
- Cost of treatment
- Cost of finding new sources of drinking water
- Public health costs
  - Hospitalization
  - Lost wages
  - Deaths



- Contaminated source water is very expensive for communities. Municipalities can incur high costs in treating contaminated water or replacing the source. Consider the following communities' experiences. In addition to treatment costs, public health costs can be exorbitant.
  - Pesticides and solvents in Mililani, Hawaii's, ground water required the system to build and operate a new treatment plant. The plant cost $2.5 million, and annual operation costs are $154,000.
  - The towns of Coeur d'Alene, Idaho, and Atlanta, Michigan, have experienced contamination of their ground water supplies. Each had to replace its water supply, at costs of approximately $500,000.
  - *Cryptosporidium* in Milwaukee's river water sickened hundreds of people and required the city to upgrade its water system. The cost of the system improvements, along with costs to the water utility, city, and Health Department associated with the disease outbreak were $89 million.
- Preventing contamination of drinking water supplies should result in reduced risk to human health from both acute and chronic ailments. Overall, the U.S. is doing a good job delivering safe drinking water to the public, but challenges remain and may increase as new waterborne disease agents and chemicals are found in water supplies. Although most people experience only mild illnesses from waterborne microbes, pathogenic organisms such as *Cryptosporidium* and some strains of *E. coli* can be transmitted to people through drinking water and cause serious illness or even death.
- The health-related costs of contamination can include lost wages, hospital and doctor bills, and in extreme cases, death.

- Aesthetic costs are also difficult to quantify. ***Aesthetics*** include the clarity, color, smell, and taste of water. Many surface water contaminants, in addition to having ecological effects, create negative aesthetic effects.
- Cigarette butts, grocery bags, scraps of fishing nets, foam coffee cups, fast food containers, soda bottles, rope, six-pack rings, balloons and balloon ribbons -- these are some of the types of materials that can be found floating in surface waters. Debris can snare boat propellers or clog cooling water intakes, causing substantial damage to boat motors. Sewage and medical wastes can contaminate beach waters and sicken swimmers. Marine animals can become caught in floating debris or mistakenly eat it. Endangered sea turtles, for example, consume floating trash bags and balloons, likely mistaking them for jellyfish.
- In the past, people mostly used soaps made from animal and vegetable fat for all types of washing. But most of today's cleaning products are synthetic detergents and come from the petrochemical industry. Many detergents and washing powders contain phosphates, which are used to soften the water, among other things.
- Harmful algal blooms, which flourish in nutrient-rich waters, have devastated the scallop industry on Long Island, killed millions of fish in Texas coastal bays, and sickened many who have eaten contaminated shellfish or visited stricken seashores.
- Under SDWA, EPA promulgates ***National Secondary Drinking Water Regulations*** (NSDWRs or secondary standards), which are nonenforceable guidelines for contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or have aesthetic effects. EPA recommends secondary standards to water systems but does not require systems to comply. However, States may choose to adopt them as enforceable standards.

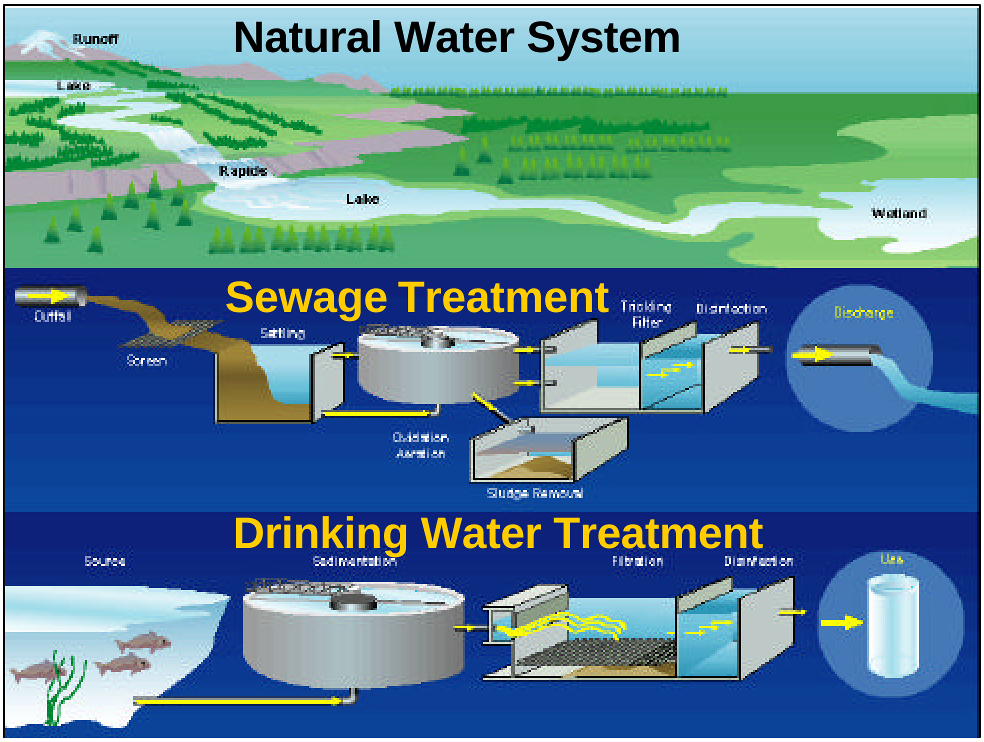

Manmade Water Management Systems
Drinking Water-Wastewater Interaction
Water Treatment
Water Resource Protection



The Deliberate and Delicate Balance between Providing Drinking Water and Wastewater Treatment

- First, there was a river. Then First Town (upper left) sprung up.
- Agriculture is established.
- First Town is now big enough for its own water and wastewater treatment plants and is contributing runoff into a storm drainage system.
- Industry moves in. This industrial facility has its own industrial waste treatment plant and also uses an injection well.
- Second Town (lower right) becomes established downriver from First Town, complete with its own water and wastewater treatment plants.
- Second Town pulls surface water from the river, just downstream from the agricultural fields that contribute runoff. Second Town also has one well.
- The arrows indicate the locations where various types of water monitoring will have to take place.


Water Treatment
Early Treatment Techniques
Wastewater Treatment
Drinking Water Treatment



- Wastewater and drinking water treatment systems both have similarities to natural water systems and the way they clean themselves.
  - o Large items or particles are removed from the water with a screen or sieve;
  - o Heavy particles are separated from lighter particles through settling, which can be natural or encouraged by chemical additions, and floating;
  - o Water is further "polished" by removing fine particles;
  - o Water is aerated to enhance biological processes (this generally only occurs in wastewater treatment); and
  - o There is a final disinfection to remove tiny viruses and protozoa that are too small for filters.

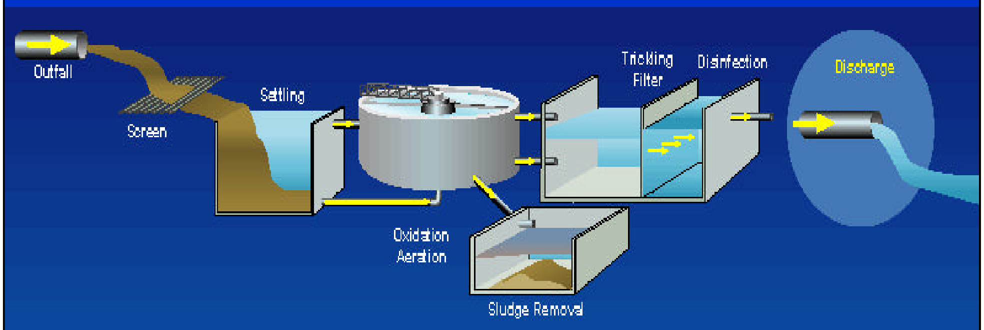
Early Treatment Techniques

- Disinfection
  - Chlorination
- Slow sand filtration
  - Large filter beds with relatively slow filtration rate, no chemical coagulation
  - Removal by sieving and "scavenging"

- Early treatment systems were aimed at both curbing water pollution and providing safe drinking water in an attempt to reduce public health risks from contaminated water. They were relatively simple and were based on many factors such as land availability, quality of raw water and the then-current understanding of causes of waterborne disease.
- Disinfection through chlorination was known to reduce microbials in water. Slow sand filtration was conducted in large beds of sand that had relatively slow filtration rates. In the slow sand process, a biological "skin" is formed in the first one-to-two inches of sand. Removal of particulates and pathogens is accomplished by sieving and scavenging by predatory organisms as water filters slowly through the sand.
- Slow sand filtration was used in North America as early as the 1600s in Spanish missions in California.


Wastewater Collection, Treatment and Disposal
DRINKING WATER ACADEMY
DWA
The Watershed Academy

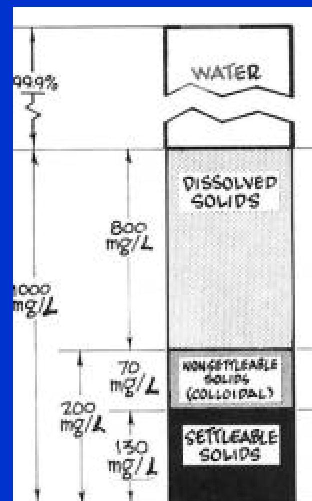
Basic Modern Sewage Treatment



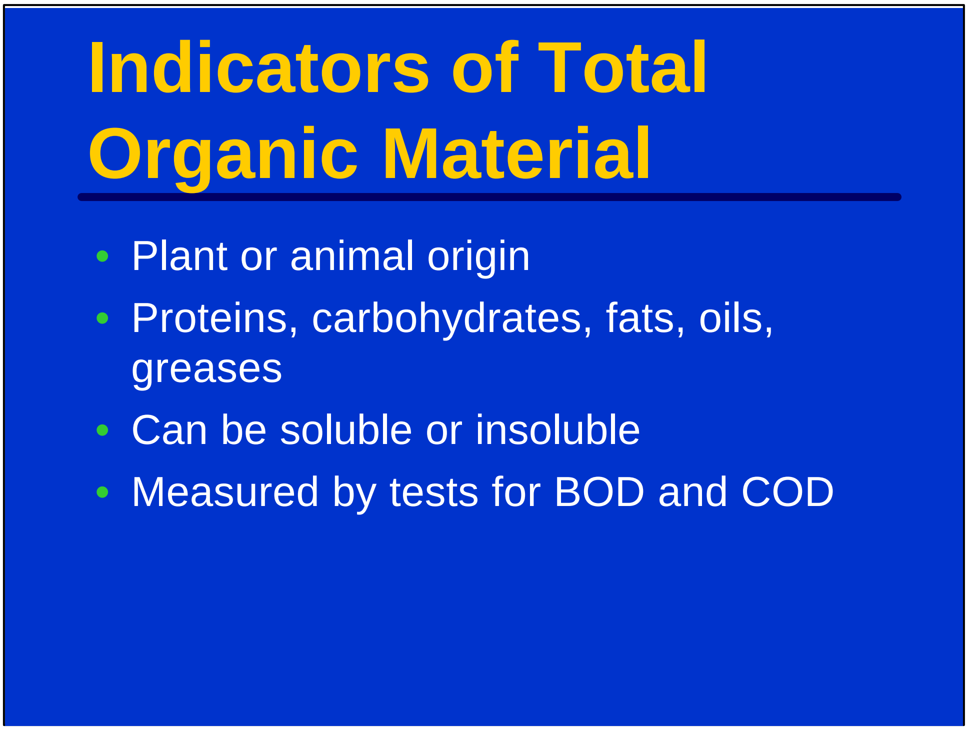
- Screening
- Primary
- Secondary
- Disinfection

Untreated Wastewater Constituents

- Water >99.9 percent
- Solids < 0.1 percent
  - Dissolved or suspended
  - Organic or inorganic
  - Nutrients
    - Nitrogen
    - Phosphorus
  - Microorganisms
    - Consumers of organics
    - Pathogens
  - Other miscellaneous
    - Grit, dirt, trash

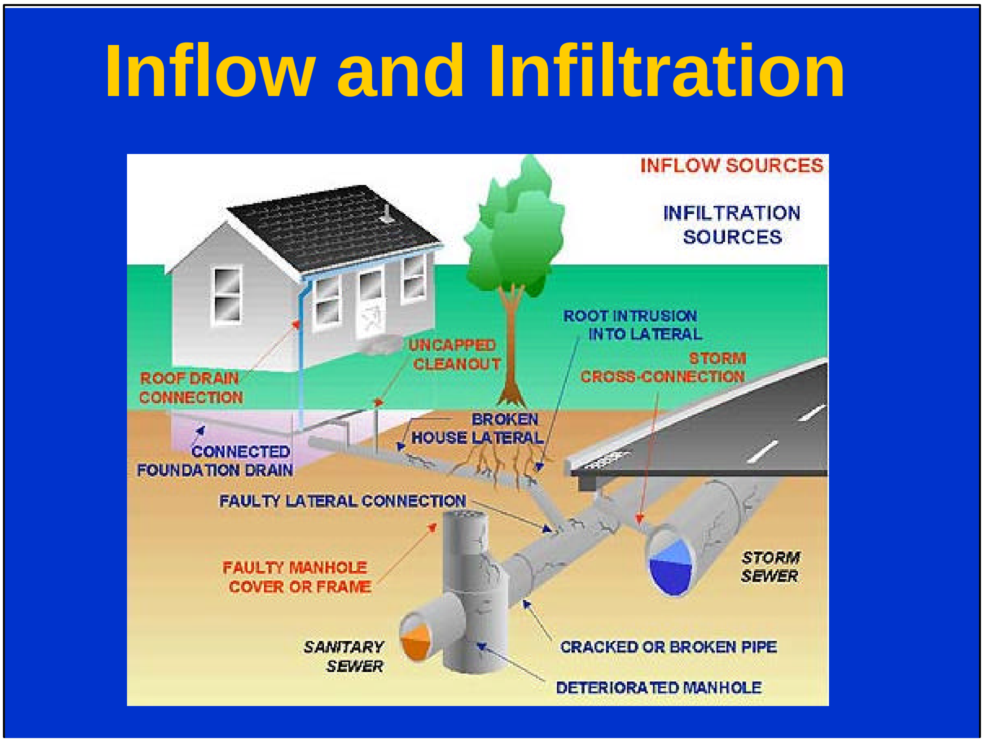


- The primary component in raw municipal wastewater is, by far, water. It comprises greater than 99.9 percent of wastewater.
- The challenge is to remove as much of the remaining 0.1 percent (the solids) as we can. Typical wastewater will have somewhere around 1000 mg/l of solids.
- Solids can be ***dissolved*** or ***suspended***. Approximately 80 percent are dissolved, with remaining 20 percent suspended. A portion of the suspended solids are heavy enough to settle in quiet water. These are referred to as ***settleable*** solids.
- Solids can be organic (plant or animal origin) or inorganic (mineral). The majority of the inorganic materials are in the dissolved phase. Most of the organics are in the solids.
- Wastewater is high in nutrients, including nitrogen (N) and phosphorus (P). Removal requirements for these nutrients is becoming more common.
- Also present in wastewater are ***pathogenic microorganisms***. These elusive disease-causing organisms are the public health component of wastewater treatment.



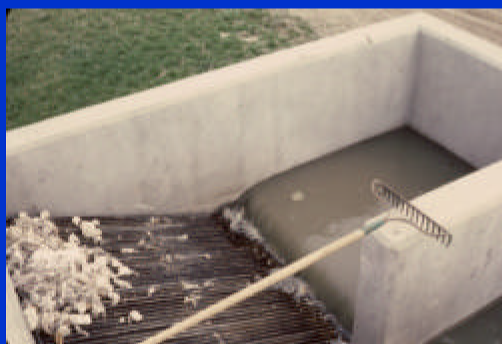
- Organic materials are carbon-based compounds. They are soluble and most easily consumed by microorganisms.
- The most common tests of organic load are the biological oxygen demand (BOD) and chemical oxygen demand (COD) tests.
- BOD is a measure of organic material based on the amount of oxygen utilized by microorganisms to convert the organic compounds (waste) to a stabilized form. BOD_5 measures dissolved oxygen over five days.
  - In raw wastewater BOD is considered the “strength” of the wastewater. A typical measurement is 220 mg/l.
  - In the effluent it is a measure of the oxygen demand placed on the receiving stream. The national secondary technology-based effluent limit is typically 30 mg/l.
- COD is a measure of organic material based on the amount of oxygen consumed when oxygen is derived from chemicals such as potassium permanganate or potassium dichromate.

- Wastewater is collected for treatment through sewers. A ***sewer*** is a pipe or conduit that carries wastewater or drainage water.
- A ***sanitary sewer*** is one that carries domestic sewage and industrial wastes, and to which storm, surface, and ground water are not intentionally admitted.
- A ***storm sewer*** carries storm water. A stormwater system includes storm drains, catch basins, storm drain manholes and manways, and stormwater pumping facilities.
- Ideally storm sewers are not connected to sanitary sewers, but those that are are referred to as ***combined sewers***. (We will cover this is more detail later.)



- ***Inflow*** and ***infiltration*** increase the amount of water in a sewer system. During wet weather periods the hydraulic capacity of combined sewer systems may become overloaded, causing overflows.
- ***Inflow*** is ***surface water*** that enters the wastewater system from yard, roof and footing drains, from cross-connections with storm drains, downspouts, and through holes in manhole covers.
- Inflow occurs as a result of storm events such as rainfall, snowfall, springs or snow melt that contribute to excessive sewer flows. Peak inflow can occur during heavy storm events when storm sewer systems are surcharged, resulting in hydraulic backups and local ponding. Inflow can also occur in sewer pipes or facilities that are subject to excessive sewage flows due to direct or indirect connections to a water body or operational inflows such as water system connections for sewer cleaning.
- ***Infiltration*** is ***ground water*** that enters sewer pipes (interceptors, collectors, manholes, or side sewers) through holes, breaks joint failures, connection failures and other openings.
- Infiltration quantities often exhibit seasonal variation in response to ground water levels. Storm events can trigger a rise in ground water levels and increase infiltration flows. The highest infiltration flows are observed following significant storm events or following prolonged periods of precipitation.

Screening and Grit Removal



Screen

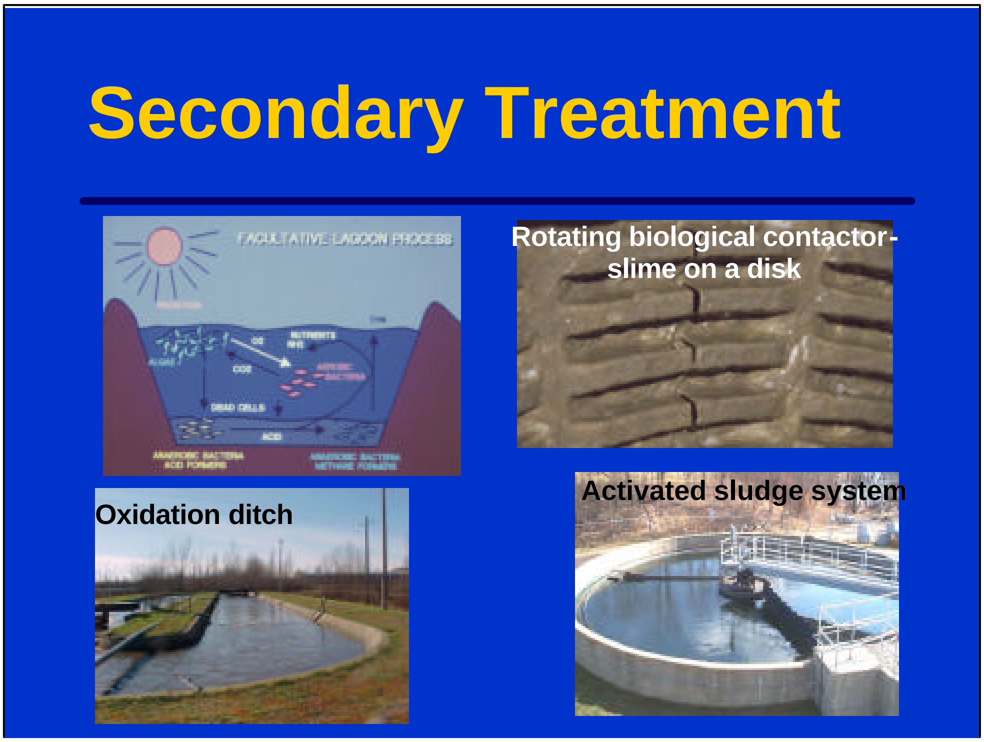
Grit removal

- One of the first steps is to ***screen*** out very large debris such as rags and roots in order to protect equipment downstream. Screenings are collected and disposed of, usually in a landfill.
- Grit is also removed by ***slowing the flow of the water*** to allow sand, rocks, glass, metals and any heavy particles to settle out. The flow is maintained at a high enough velocity to keep organic waste materials in suspension. The materials are then removed, and sent to a sanitary landfill for disposal.
- This process can reduce wear on downstream equipment from abrasion or excessive solids build up, particularly in clarifier and digesters. This is particularly important for systems with combined sewers, as they carry excessive grit from roadways
- Types of grit removal:
  - Horizontal flow
  - Aerated chamber
  - Vortex chamber
  - Centrifuge

Primary Treatment

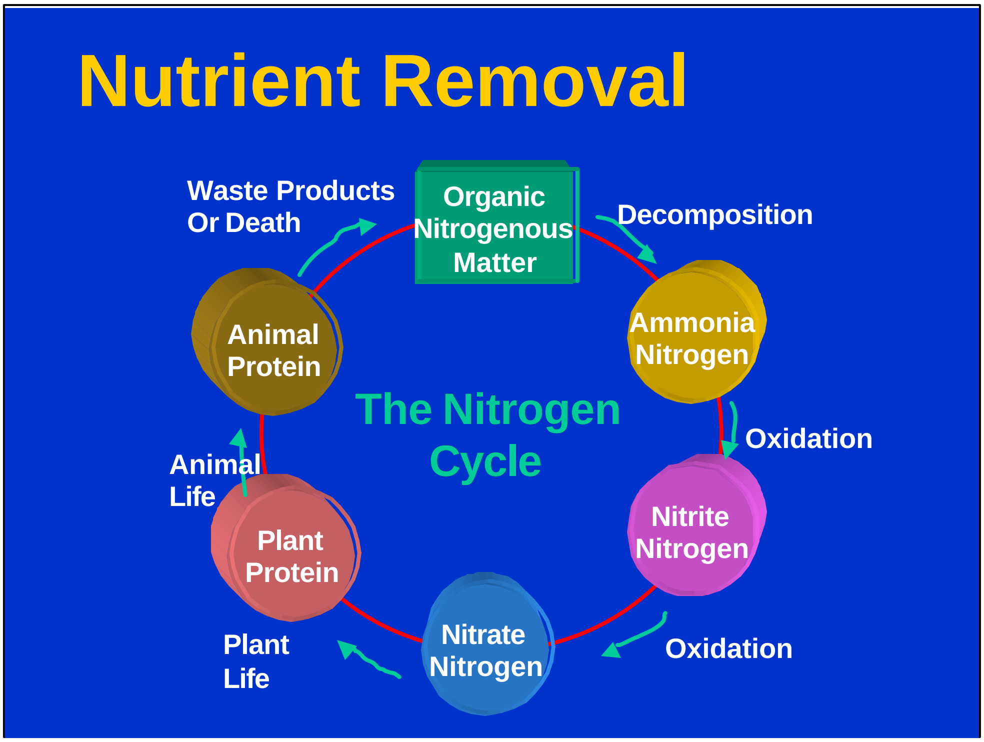
- Removes pollutants that settle or float
- Primarily a physical process
- Once considered adequate, now considered a good first step

- ***Primary treatment*** is predominantly a ***settling*** process. The flow is slowed to allow settling. Approximately 60 percent of suspended solids and 35 percent of BOD can be removed.
- Sludge settles and is removed by mechanical scrapers or pumps. Floating material such as fats, oils and greases (FOG) are collected by a skimmer.



- ***Secondary treatment*** is ***not just biological***, but biology plays major role. The secondary process typically provides an aerated environment for microorganisms to consume organic material not removed in the primary.
    - o ***Aeration*** is process that ***promotes biological degradation*** of organic matter in water. The process may be passive (as when waste is exposed to air), or active (as when a mixing or bubbling device introduces the air).
- Soluble BOD is easily consumed and converted into an insoluble form (from waste or "food," to bodies of microorganisms or "mass") that can settle and be removed.
- Key constituents for treatment:
    - o Food: waste from human activity, organic material, BOD;
    - o Microorganisms for biological decomposition consume food and turn it into "mass" to settle out later;
    - o Oxygen for microbes and chemical reactions. In simpler systems like lagoons this can come naturally from air or algae, in mechanical systems, aerators provide air; and
    - o Time for biological and physical (settling) processes. Inadequate time could result in inadequate removal of pathogens, BOD and organics.
- Examples of systems used for secondary treatment include:
    - o Trickling filters;
    - o Activated sludge;
    - o Rotating biological contactors; and
    - o Lagoons and ponds.

- The terms ***"tertiary" or advanced treatment*** refer to additional treatment processes beyond secondary processes. Many processes can fall under this umbrella. We will briefly discuss *disinfection* and ***nutrient removal***.
- ***Disinfection*** either inactivates or kills pathogens. Chlorination kills and ultraviolet light inactivates. Treatment systems test for coliform and fecal coliform as indicators of potential pathogens.
- Water must get adequate ***contact time*** with disinfectants before discharge. The treatment plant may need to dechlorinate so as not to affect the receiving stream. If disinfection is not completely effective, organisms can be "stunned" and regrowth can become an issue.
- As treated effluent travels through channel, it passes the UV unit and organisms are "inactivated."
- Adding ***ozone*** is also a method of disinfection. However, it is used more frequently in drinking water treatment.



- Nitrogen may exist in many forms in wastewater. Typically, nitrogen is found in the organic (plant/animal life) and ammonia/ammonium forms. Nitrification is the process in which ammonia nitrogen is oxidized using oxygen available in the water to nitrate.
- Once in the nitrate form, in the lower regions of the lagoon (if not aerated from the bottom), anaerobic conditions (now termed “anoxic” or without oxygen) exist. Bacteria in these regions convert the nitrate to nitrogen gas that will release into the atmosphere. Assimilation occurs when certain microbes assimilate or absorb the ammonia nitrogen into cell mass.
- Chemical and physical processes such as breakpoint chlorination, ion exchange and air stripping are available but not as common for nitrogen removal.
    - Physical – treated wastewater effluent is applied to soil (land application or I/P cells or drainfields). Phosphorus adsorbs to soil particles.
    - Chemical – aluminum sulfate is added, precipitation reaction occurs and aluminum phosphate settles out.
    - Biological – alternating anaerobic and aerobic stages encourages bacteria to take up phosphorus.

- Once the wastewater is treated, the treated effluent needs to be discharged. There are several options:
  - Controlled ***surface water discharge*** provide the flexibility to discharge when effluent is cleanest or when the stream is capable of handling flows (hydrograph), or to store until irrigation season. These discharges require a NPDES permit.
  - ***Ground water discharges*** can take the form of direct injection or placing water so that it will seep slowing into the ground water, such as percolation pond or infiltration bed. This may require a ground water discharge or underground injection control permit.
  - ***Land application*** is also a method of disposal. When properly designed and operated, there should be no degradation of receiving water. ***Spray irrigation*** requires storage until irrigation season in cold climates. It must also consider the soil's ability to accept water and the crop's ability to take up nutrients (growth cycle). Total retention requires very large storage ponds and is generally used only in arid climates as net evaporation must exceed precipitation plus wastewater inflow. One interesting application is ***snowmaking***. In the photo above, a wastewater lagoon discharges to a snow making machine. The effluent is pressurized with high press air and then released into the atmosphere under the right conditions of temperature, humidity, and wind to make snow.
  - Other ***beneficial reuses*** for effluent include ***aquifer recharge*** and ***irrigation***.

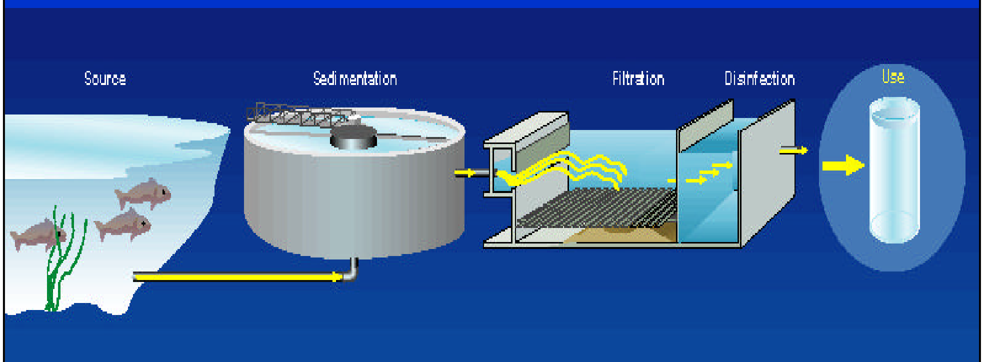
Biosolids Handling - Processes

- Conditioning
  - Coagulant addition
  - Heat treatment
- Thickening
  - Gravity thickener
  - Dissolved air floatation
- Dewatering
  - Belt filter press
  - Sludge drying beds
  - Centrifuge
- Stabilization
  - Aerobic digester
  - Anaerobic digester
- Reduction
  - Incineration
- Disposal or reuse
  - Land application
  - Landfilling
  - Composting

- Solids removed from the raw sewage (aka “sludge” or biosolids) by the wastewater treatment process must be stabilized and ultimately either disposed of or reused. There are a number of solids handling processes.
  - ***Conditioning*** – treatment of the sludge with chemicals or heat to improve dewatering characteristics.
  - ***Thickening*** – separation of as much water as possible by physical means such as gravity or flotation process.
  - ***Dewatering*** – further separation of water by subjecting the sludge to vacuum pressure or drying processes.
  - ***Stabilization*** – stabilization of the organic solids so that they may be handled or used as soil conditioners without causing a nuisance or health hazard through digestion processes.
  - ***Reduction*** – reduction of the solids to a stable form by wet oxidation processes or incineration.
  - ***Disposal or reuse*** – becoming increasingly more difficult to find means of disposing or reusing sludge as regulations are becoming more strict.


Drinking Water
Treatment and Use

Modern Drinking Water Treatment

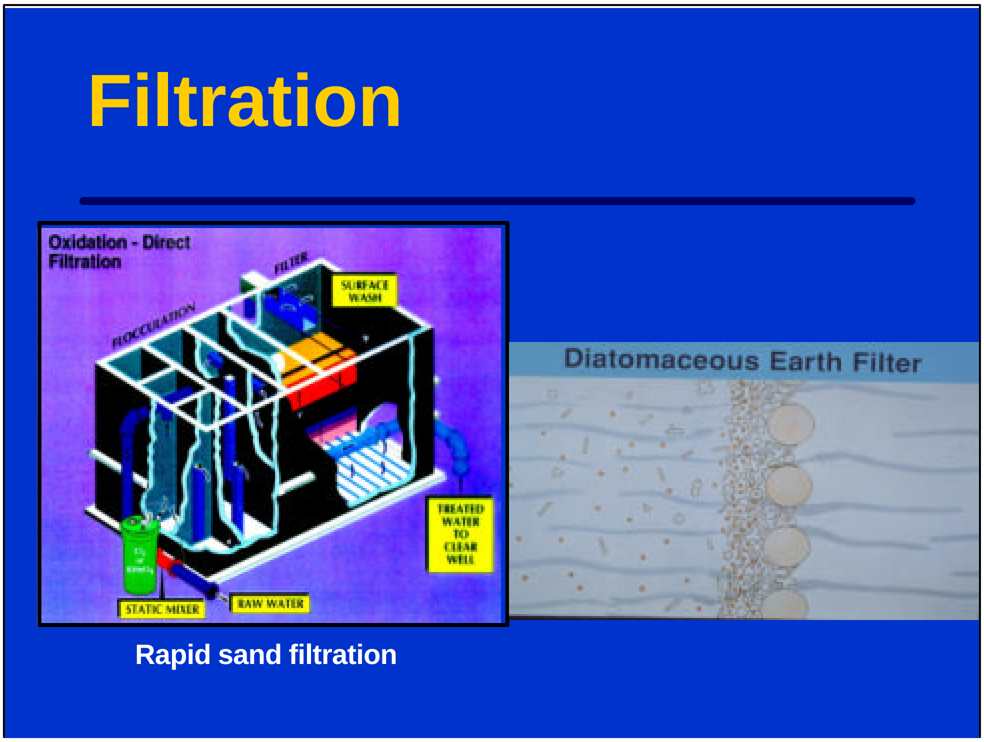


Why Treat Drinking Water?

- To make water safe
- To make water more attractive
  - Turbidity and color
  - Taste and odor
  - Staining
  - Hardness

- The purpose of drinking water treatment is twofold.
  - Primarily, we need to ***make water safe*** for consumption.
  - Secondarily, we want to make it more ***appealing to consume and use***. While appearance, taste and odor might not immediately seem like health concerns, they certainly can be. That is because it has been shown repeatedly that consumers will find other sources of drinking water if their public supply doesn't appeal to them. Often those sources are unprotected, unsampled and unsafe. In addition, although some contaminants in water may not affect health, they may make the water less palatable or create a nuisance by staining fixtures or laundry.
- Today's discussion will focus mainly on water treatment processes that make water safe for human consumption

- Drinking water treatment is concerned with the same contaminants we discussed for wastewater treatment:
  - o Organic material;
  - o Pathogens; and
  - o Nutrients and other inorganic chemicals.
- Due to their occurrence in drinking water at levels that can affect acutely and because they often cause serious disease and death, a major focus of water treatment is pathogens.
- Pathogens can be removed from the water (typically by settling and filtration) or can be killed or inactivated (typically by disinfection with chemicals or UV light).
- As we discussed, ***settling*** is simply the removal by letting the water slow down so heavier particles can be removed by gravity. Often chemicals are added to allow particles of like charges to become destabilized, to from flocs, and to settle out.
  - o In order to remove smaller and lighter particles (those with lower specific gravities) chemicals often have to be added that allow charged particles to become neutrally charged or otherwise "destabilized" so they can come together and settle out. Chemicals are added to the raw water, usually metal salts such as alum or ferric chloride, and rapidly mixed, then slowly mixed to form flocs that will settle. The drawing shows a rectangular sedimentation basin where clarification occurs. Note the sludge removal device.

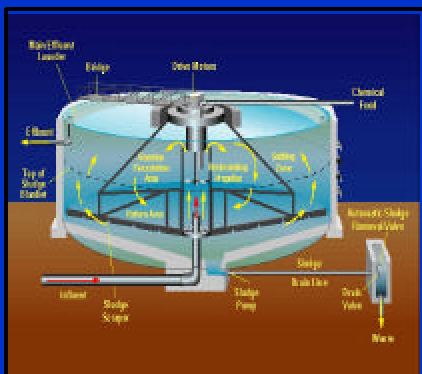


- The fundamental system that removes particulate matter is filtration, the most common filter being a granular medium of a certain size and depth. Examples of filtration technologies are:
  - ***Rapid sand filters*** move water through sand. An organic mass or “skin” forms on and in the first couple of millimeters of sand and the particles, including pathogens, are sieved out of the water as it passes through this skin. A German term, “schmutzdecka” meaning “dirty skin” has been applied to this organic layer. Rapid sand filters are only effective where chemicals such as alum have been added to form floc.
  - ***Diatomaceous earth*** (DE) filters are effective for removing turbidity and pathogens from relatively high quality (low turbidity) water. DE is fed as water moves through a septum covered with a fabric that holds the DE in place. After a DE coating is built up the DE will remove turbidity by sieving. DE is continuously fed during the treatment process as “body feed” allowing the layer to thicken and to continue to remove particles without plugging up.

- There are alternative methods of filtration that can be effective as well. SDWA regulations require that such methods be pilot tested to show how effective they are in removing *Giardia* and *Cryptosporidium* cysts.
- This is a photograph of a small surface water system that used ***cartridge filters*** for filtration. There are two parallel treatment trains that have a roughing filter followed by a 1 micro filter, then followed by UV light disinfection.
- A second photograph shows a pre-treatment step in an Alaska native surface water system. The green unit is a ***pressure filter*** that serves to take out the largest particles (without chemical addition) before the water passes to more effective filters.
  - Some Alaska systems that are located north of the Arctic Circle often only have two or three months, or less, in the summer when they can produce water because it is normally frozen.
  - The second and third steps of the removal process are not shown. First, the water passes through 10 micron cartridges in open housing. Then the water passes through a pair of 1 micron bag filters. This is an Alaska “fill and draw” system. That is a system that produces water until the storage tanks are full and is then shut down, sometimes for months, until most of the water is used from storage.
- The third photograph shows a micro-filtration membrane system. In this system a high quality surface water is passed through the walls of hollow membranes through pores of 1 micron is size. The water is then passed through granular activated carbon contactors to remove organics that can cause tasted, odors and disinfection by products. Finally, disinfection is applied.

- ***Distillation*** is a treatment process that removes almost everything from most waters. It is energy intensive and costly. The above photograph is of a major distillation plant in the Virgin Islands. Sea water is used as a source, the water is distilled, disinfected with chlorine, then delivered. The distillation units are put under partial vacuum to lower the boiling point of water and waste heat from a power plant is used for heating the water.
- Often, where water seems to be the most plentiful, drinking water is very difficult to find and expensive to treat.

Removing Chemical Contaminants



Enhanced lime softening

Activated alumina

- Numerous technologies are used to remove chemical contaminants. Most of these technologies are capable of removing several contaminants. Note, also, that some of the technologies we discussed for removing pathogens also remove chemical contaminants.
  - Conventional treatment
  - Lime softening
  - Activated alumina
  - Ion exchange
    - Cation
    - Anion
  - Aeration
  - Membranes
  - Distillation
  - Biological treatment
  - Corrosion control
- ***Lime softening*** is typically used to removed hardness (mostly calcium and magnesium) from water. It can also remove metals and other IOCs (arsenic), radiological contaminants, and disinfection byproduct precursors (total organic carbon).
- ***Activated alumina*** has been used mostly for fluoride removal but is now being used and considered for use for removal of arsenic. It can be regenerated and the media reused, however, in many cases it is more economical to load the media with the contaminant, then replace the media with fresh, and throw away the spent media.

Removing Chemical Contaminants

Aeration

Adsorption

- ***Ion exchange*** is typically used to remove nitrate from drinking water. The water is passed through a medium (anion exchange resin) that exchanges chloride for the nitrate. Periodically the resin is renewed by flooding it with a saturated salt solution that reestablishes the chloride ions at their original sites on the resin. Then the treatment process can be resumed.
- This process is very similar to ***ion exchange softening***, a treatment common in many households that have hard water. However, in the case of softening, a cation exchange resin is used and the calcium and magnesium ions are exchanged for sodium. Regeneration occurs in a similar manner, however, the sodium is replaced rather than chloride.
- ***Aeration*** is effective for removal of volatile organic contaminants. It is probably more commonly used for removal of secondary contaminants such as hydrogen sulfide gas or for oxidation of iron prior to removal by filtration.
- A variety of contaminants can be removed by flowing water through media that have affinity for the contaminant. The contaminant ***adsorbs*** to the media and is removed from the water.
  - Granular activated carbon (GAC) adsorbs VOCs, SOCs, and disinfection byproduct precursors.
  - Granular ferric hydroxide is a medium that adsorbs arsenic.

- Other chemical contaminants can be sieved or strained out by forcing the water through a porous ***membrane*** of defined pore size. The contaminants that will be removed depend upon the pore size of the membranes and the charges on the contaminants.
- ***Reverse osmosis*** can remove most contaminants and produces a near-distilled water quality.
- ***Micro-filtration*** with membranes can be used for removing arsenic when coupled with addition of coagulant and coagulation. The photo shows membrane filters in a surface water treatment plant.

Corrosion Control

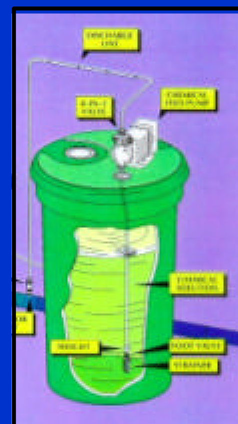
- Adjustment of water chemistry
  - pH
  - Alkalinity
- Coating mains and plumbing

Corrosion control

- Corrosion control treatment differs from most drinking water treatment techniques used for public health protection. The contaminants that cause the health risks are typically lead and copper that are found in plumbing systems of homes rather than in the raw water. Therefore, the goal is not to get lead and copper out of the raw water.
- Instead, the water must be treated, before distribution, to make it as non-corrosive as possible so that it will not dissolve the lead and copper from the plumbing materials in homes and other buildings. Usually this involves adding one or more chemicals to the water prior to distribution.
- Often soda ash or other chemicals that raise both pH and alkalinity is added. Also orthophosphate solutions or blends of orthophosphate and polyphosphate can be added to coat plumbing materials.

Disinfection

- Chlorine
- Chloramines
- Ozone
- Chlorine dioxide
- Ultra violet light



- As we discussed, filtration removes some of the pathogens from drinking water. However, for surface waters where pathogens are most common, SDWA regulations require a certain percentage of reduction to be attained through a combination of filtration (previously discussed) and ***disinfection***. Disinfection either inactivates or kills pathogens and other microorganisms in drinking water. This slide lists the most common methods.
- ***Chlorination*** is far and away the most common method of disinfection, followed by ***chloramination*** (chlorine with a small amount of ammonia).
- The drawing is a ***liquid chlorination*** system. A chlorine solution, similar to household bleach but without any other whiteners and brighteners often found in laundry products, is pumped into the raw water stream with a metering pump at all times water is being produced. These kinds of units are often found at the well house and operate at all times the well pump is operating. The metering pump is on the same electrical circuit as the well pump so water cannot be produced without it being chlorinated. A flow sensor will shut the pump off if there is no flow in the line.
- The photo shows two pressure cylinders that contain chlorine gas. The gas is extremely toxic and dangerous so installations are designed to make sure disinfection occurs while minimizing the possibility of spills, leaks and accidents. The two blue colored boxes are vacuum operated valve systems that open when a vacuum is pulled on the lines to the cylinders. If the line breaks, the vacuum is lost and the valve closes keeping leaks from occurring. The system is also designed to sense the point at which one cylinder becomes empty and switches to the second cylinder to keep from having any interruption of disinfection. This is called "automatic switch-over."
- Note that although drinking water and wastewater treatment plants both disinfect, they have different goals reagarding residual chlorine. With drinking water, it is desirable to have some residual chlorine is the distribution system. With wastewater, however, the goal is to dechlorinate as much as possible before discharging to a surface water body.

- ***Ozone*** is becoming more and more common as a disinfectant. It is often used in water bottling plants because is leaves no residual that could cause bad tastes or odors. It is also used in surface water treatment plants to enhance the filtration process and to help remove disinfection byproduct precursors and other organic compounds.
- The photograph is of ozonators at Whiting, Indiana. These were put in about 1948 and are still functional.
- ***Ultraviolet light***, which we discussed during the section on wastewater treatment, can inactivate *Cryptosporidium* cysts, therefore, UV is likely to become more commonly used on surface water systems to complete the multiple barrier protection process for this organism.

Removal of Secondary Contaminants

Iron and manganese removal

Package plant for hydrogen sulfide gas removal

- ***Secondary contaminants*** include those that affect the turbidity, color, taste, odor, or hardness of the water. These contaminants affect the appearance of the water, but do not pose a direct threat to health. [Secondary contaminants should not be confused with wastewater secondary treatment, which was discussed earlier.]
- Secondary contaminants can have an indirect effect on health because, when the water is not "attractive," people will find another source. Often those alternative sources are not monitored and are not safe.
- Common technologies include those we discussed earlier: filtration, enhanced coagulation, aeration, lime softening, cation exchange, adsorption, membranes, and combinations on these technologies.
- Water can be treated for removal of iron and/or manganese by ***oxidizing*** the metals to their insoluble forms, then removing them through ***filtration***. One photo above shows a building that contains such a plant. The tower on the far side of the building is where the raw water is aerated (i.e., oxygen is added) in order to oxidize the metals. Chlorine and, sometimes, potassium permanganate ($KMnO_4$) may be added as well to ensure oxidation.
- The other photo is an example of a package plant for use at small systems to remove hydrogen sulfide gas. Water is pumped from the well to a ***tray aerator*** on top of the plant. The aeration of the water effectively removes the gas. The water is stored in the back part of the unit, then disinfected and pumped to the distribution system. This plant can be moved on-site as a complete unit.

Transmission, Distribution, and Pumping Facilities

- Water mains
- Pumping facilities
- Appurtenances
  - Hydrants
  - Water meters
  - Valves and backflow prevention devices

Source: Carl Ambrose: New York City DEP

- After treatment, finished water is ready to be delivered to consumers. For most water systems, the distribution and transmission of water requires a larger capital investment and more operating resources than other components of the water system.
  - ***Transmission*** pipes bring water from the source to treatment or from treatment to the distribution systems.
  - ***Distribution*** pipes deliver water to the customer. These pipes are also known as "***water mains***." Many water systems also include ***booster pumps***, which help keep the system pressurized. Structurally sound mains and pumping facilities are critical to guard against public health risks. If pressure is lost or if negative pressure is induced, contaminated water or sewage can be pulled back into the system through leaks. In addition, mains must be in good condition because failure could leave a community without water until the outage is repaired.
- Distribution systems also include ***appurtenances*** that help safeguard public health.
  - ***Hydrants***, aside from fighting fires, are used to flush stagnant water from the system.
  - ***Water meters*** help prevent overuse of water and provide the system with data on unaccounted water use, which may help the system identify leaks.
  - ***Valves*** are necessary to direct the flow of water or close off a water line for maintenance or repairs. ***Backflow prevention devices*** help ensure that contaminated water that may originate at commercial establishments, residences, or interconnected distribution networks does not contaminate the water system.

Storage

- Pressurizes the distribution system which keeps contaminants out
- Allows system to meet peak demands
- Protects pumps

- Almost all water systems include facilities to store ***finished water***, or water that is ready for delivery to the customer. ***Storage*** can be in ground level tanks or elevated tanks. Small water systems often use small pressurized tanks (***hydropneumatic tanks)*** that use electrical power rather than elevation to maintain pressure in the distribution system.
- Adequate storage capacity is important because it ensures the positive ***water pressure*** necessary to prevent contaminants from being drawn into the distribution system. By contrast, sewer pipes operate at ambient pressure levels.
- Periodic rehabilitation of storage facilities is necessary to prevent entry and growth of microbiological contaminants in the storage facility and to maintain structural integrity.
- Storage is also necessary because it allows systems to provide water during periods of peak usage and ensure adequate pressure to meet fire flow requirements. Many small water systems do not have storage or other facilities that are adequate for fire protection purposes.